Impact of surface passivation on UV stability of bifacial mc-Si PERC solar modules

Ben X. J. Yu¹, Jean-Nicolas Jaubert¹, Huade Wu¹, Jian Wu¹, Fangdan Jiang¹, Guangchun Zhang¹, Dylan Colvin²,³, Nafis Iqbal²,³, Kristopher Davis²,³, Thomas Moran⁴, Bryan Huey⁵, Alan Curran⁵, Laura Bruckman⁵, Jennifer Braid⁵, Roger French⁵

¹CSI Reliability Research, Canadian Solar Inc., Suzhou, Jiangsu, China
²Materials Science, University of Central Florida, Orlando, FL, USA
³FSEC Energy Research Center, Orlando, FL, USA
⁴Materials Science, University of Connecticut, Storrs, CT, USA
⁵Materials Science, Case Western Reserve University, Cleveland, OH, USA

Abstract—Many research show that UV degrades the solar cell and module power. In this work, we study the UV stability of mc-Si bifacial PERC solar modules with different industrial silicon nitride (SiNx) passivation. We find that with exposure to UV at 60 °C, both Voc and Jsc decrease then stabilize. The quantum efficiency analysis shows decreased response in both short (blue loss) and long (base collection loss) wavelength range. It infers that deteriorations were not only at passivation layers, but also in the silicon bulk, caused by UV-induced degradation and possible LeTID. No significant difference in degradation has been found between front and rear passivation, or between different PECVD, respectively. While thermal oxidation process employed in mass production effectively improved UV resistance.

Keywords—PERC, Multicrystalline, Bi-Facial, UV-induced degradation, Passivation, PECVD, Thermal oxidation

I. INTRODUCTION

Encapsulation with high UV transmission has been used by solar panel manufacturers to harness spectral response of solar cells in the shorter wavelength range. However, Sinha et al. reported induced UV exposure caused equivalent power loss ranging from commonly seen 0.5%/y up to 8%/y for raw solar cells with various technologies after exposure to UV irradiation of 8.92 MJ/m²-nm at 340 nm [1]. Witteck et al. concluded that UV photons broke Si-H bond and increased the recombination at the passivation surface [2,3]. While Ye et al. found that UV light triggered the generation of defect in the bulk of solar cells [4].

Since passivated emitter rear contact (PERC) is currently the most dominant solar cell technology in PV market and is anticipated to be so in next few years [5], this work focuses on degradation of bifacial PERC with common silicon nitride (SiNx) passivation stacks. We study the impact of passivation property on the UV performance of multicrystalline (mc-Si) PERC solar cells and aim to find the best strategies to mitigate UV-induced degradation.

II. EXPERIMENT

A. Sample preparation

Boron-doped mc-Si PERC cells were fabricated in an industrial PERC production line. A layer of Al₂O₃ were deposited on the rear surface of cell via atomic layer deposition (ALD). The front and rear surfaces were then further coated with different designs of SiNx:H by either microwave remote or RF direct plasma–enhanced chemical vapor deposition (PECVD) as shown in Figure 1. In particular, SiOx were introduced by thermal oxidation.

Fig. 1. Scheme of fabricated bifacial PERC cells with different front passivation.

Four groups of one-cell minimodules composed of the same glass, encapsulant, and backsheet were prepared using fabricated PERC cells. The groups of minimodules differ on the basis of passivation surface irradiated by UV, as shown in Table 1 and Figure 2. G1, G2, G3 are regular modules with cell front passivation on the glass side, while G4 has the same PERC cell as G1 but with cell rear passivation on the glass side. The UV

[Image of Scheme of fabricated bifacial PERC cells with different front passivation]
light source was metal halide lamp with visible lights not being filtered.

Fig. 2. Images of a G1 minimodule and a G4 minimodule, with cell front on glass side and cell rear on glass side, respectively.

TABLE I. Passivation Stacks, Shaded Area Indicating Surface Exposed to UV Irradiance

<table>
<thead>
<tr>
<th>Group</th>
<th>Irradiated Surface</th>
<th>Passivation</th>
</tr>
</thead>
<tbody>
<tr>
<td>G1</td>
<td>Cell front</td>
<td>SiNx (Remote) Al2O3/SiNx (Direct)</td>
</tr>
<tr>
<td>G2</td>
<td>Cell front</td>
<td>SiNx (Direct) Al2O3/SiNx (Direct)</td>
</tr>
<tr>
<td>G3</td>
<td>Cell front</td>
<td>SiNOx/SiNx/SiOx Al2O3/SiNx (Direct)</td>
</tr>
<tr>
<td>G4</td>
<td>Cell rear</td>
<td>SiNx (Remote) Al2O3/SiNx (Direct)</td>
</tr>
</tbody>
</table>

UV transparent EVA was used on the glass side, while UV cut-off EVA was used on the backsheet side to avoid the effect of reflected UV light from white backsheet.

B. UV aging and characterizations

To stabilize the test samples, B-O light induced degradation and LeTID preconditioning were performed, the minimodules were exposed to 10 kWh/m² of sunlight and then injected with current of I_sc at 85°C for 48h [6]. After preconditioning, the minimodules were short-circuited and placed under metal halide lamp with stepwise UV exposure up to a total UV dose of 210 kWh/m² at 60°C.

Quantum efficiency (Enlitech), Suns-Voc (Sinton) curves, electroluminescence (EL) and photoluminescence (PL) images of minimodules were obtained each step.

III. RESULTS AND DISCUSSION

A. Pseudo I-V results

The short circuit current density (Jsc) was derived by spectral response (SR_{sample}) results from external quantum efficiency (EQE) analysis using Equation 1.

\[ J_{sc} = \int E_{AM1.5}(\lambda) \cdot SR_{sample}(\lambda) \cdot d\lambda \]  \hspace{1cm} (1)

Where \( E_{AM1.5} \) is power density of solar spectrum AM1.5 and \( \lambda \) is wavelength.

Suns-Voc measured irradiance dependent Voc values and produced series resistance (Rs) free pseudo I-V curves. Then Jsc obtained from EQE were used to adjust current density in the Suns-Voc results and produced actual Rs impacted pseudo I-V curves as shown in Figure 3.

Finally, I-V features could be extracted from Jsc corrected pseudo I-V curves and the results are shown in Figure 4. G1, G2, and G4 shows similar degradation pattern, with decreased Voc and Isc. While G3 has the least UV-induced degradation.

The passivation layers of samples in four groups all have similar optical properties, with refractive index of 2.1. Although passivation in G1 and G2 are both SiNx, samples in G2 prepared by RF direct PECVD had higher hydrogen concentrations and more compact passivation than G1 prepared by microwave remote PECVD. Since there is no obvious difference in degradation between G1 and G2, the concentration of hydrogen and compactness of SiNx seem not to have significant impact on UV-induced degradation. Moreover, with the same chemical
components of topmost passivation layer, no significant difference is observed between G1/G2 and G4, i.e., front and rear. However, G3 shows much less degradation when comparing with other three groups, it can be concluded that thermal oxidation can effectively mitigate the UV-induced degradation.

B. Spatial response

Figure 5 shows the average EQE curves of 4 samples of G2 and G4, respectively. Decrease of EQE in the wavelength range of 400 to 1000 nm has been observed. It can be inferred that deterioration were not only at passivation surface, but also in the silicon bulk.

![Fig. 5. Mean EQE curves of 4 samples per group.](image)

C. EL, PL

Figure 6 shows typical EL and PL images of module before and after UV exposure. No defects have been spotted. Further analysis is required to investigate the mechanism of UV-induced degradation.

![Fig. 6. EL and PL images of G4-2 after preconditioning and UV 210 kWh/m².](image)

D. Chemical composition analysis

Composition analysis including coring for element depth profiles, X-ray photoelectron spectroscopy (XPS), Fourier Transform Infrared Spectroscopy (FTIR), and Time-of-Flight Secondary Ion Mass Spectrometry (ToF-SIMS) are on-going for further investigation of degradation mechanism.

IV. Conclusion

We find that thermal oxidation of passivation layer could improve the UV stability of PERC solar module, while similar degradation has been observed between Remote and direct PECVD, front and rear passivation, respectively. Results shows that deteriorations were not only at passivation layers and interfaces, but also in the silicon bulk. The degradation most likely were induced by UV photons.

REFERENCES


