Modelling of Bifacial Silicon Heterojunction Solar Cells for Arctic Applications

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***Abstract* — Bifacial photovoltaics can achieve up to 25-45% bifacial gain in Arctic conditions due to high-albedo snow cover and high proportion of diffuse light. To study the performance of solar cells at high latitude, high air mass, low temperature, and high angle of incidence conditions must be considered. Modelling was performed in SunSolve to study the angular performance of bifacial silicon heterojunction (SHJ) solar cells with various surface textures and under several air masses. Increased reflectivity reduced the external quantum efficiency (EQE) at high angles, while longer path length through front surface films increased UV losses. Simulated and measured EQE of surfaces with pyramidal texturing were compared, and similar trends were observed with increasing angle. These results will help to inform future designs of heterojunction bifacial cells optimized for Arctic conditions.**

I. Introduction

Many northern and remote communities rely on diesel power generators, but diesel is expensive and has a high impact on fragile Arctic environments. Bifacial photovoltaics, which absorb light from the rear in addition to the front, present a clean and potentially cheaper alternative, with a greater energy collection than standard monofacial solar panels.

The North presents favorable conditions for bifacial solar installations due to typically higher albedo (caused by a high degree of snow cover), high proportion of diffuse light, and low temperature, which is ideal for PV module efficiency. These locations also present different operating conditions for solar installations, namely high air mass (AM) and high angle of incidence (AOI). Performance of solar cells at high latitude will benefit from characterization and optimization under these altered environmental conditions.

Silicon heterojunction (SHJ) solar cells can be easily adapted to bifacial applications, and currently hold the record for silicon solar cell efficiency at 26.7% [1].

II. Simulation

To determine the optical behavior of solar cell designs, simulations were performed using SunSolve™, a Monte Carlo ray-tracing software by PV Lighthouse that evaluates thin-film and surface texturing optical effects. Simulations were run with a total of 5×10^6 rays for each angle with 10-nm wavelength steps over the absorption range of c-Si. The model includes shading losses from fingers and busbars, but does not account for any of the cell's electrical properties. Figure 1 depicts the bifacial cell layer structure used in this work.

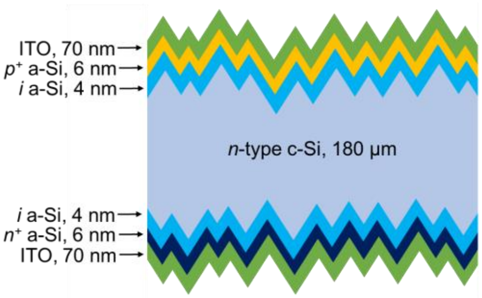

Fig. 1. Schematic of the simulated bifacial silicon heterojunction solar cell layer structure with random pyramidal surface texturing on both faces.

The optical properties of the hydrogenated amorphous silicon (a-Si:H) thin films depend strongly on their deposition parameters, which may not be well-modelled in simulation but can have an impact on final cell performance. Therefore, ellipsometry measurements of PECVD-deposited doped and intrinsic a-Si:H layers were taken, and the Tauc-Lorentz model (the commonly accepted method to simulate a-Si:H), was applied. These results were used as model inputs, while ITO parameters were taken from Holman *et al*. [2].

To study the effect of texture on cell performance for varied angles, four surface morphologies were studied: planar, random upright cones, periodic inverted pyramids, and random upright pyramids. External quantum efficiency (EQE) was simulated for each surface texture at angles of incidence (AOI) from 0° to 80°, as shown in Figure 2. Although inverted pyramids had approximately 0.1% higher average reflectivity compared to upright pyramids, the results were otherwise similar and inverted pyramids are therefore not shown.

As expected, reflectivity increases across the spectrum with increasing angle for all textures. The planar solar cell (Fig. 2a) has the highest reflectivity, particularly in the UV and near IR. The addition of surface texturing reduces the overall reflectivity for all AOI.

Figure 2c includes the measured EQE performance of a bifacial SHJ solar cell with random upright pyramidal texturing on both faces for AOI up to 50°. Measurements were taken between cell fingers, then adjusted to account for anticipated shading losses of the fingers and busbars.

As in the simulated EQE, the measured EQE is reduced under higher AOI, especially in the UV and the IR. However,

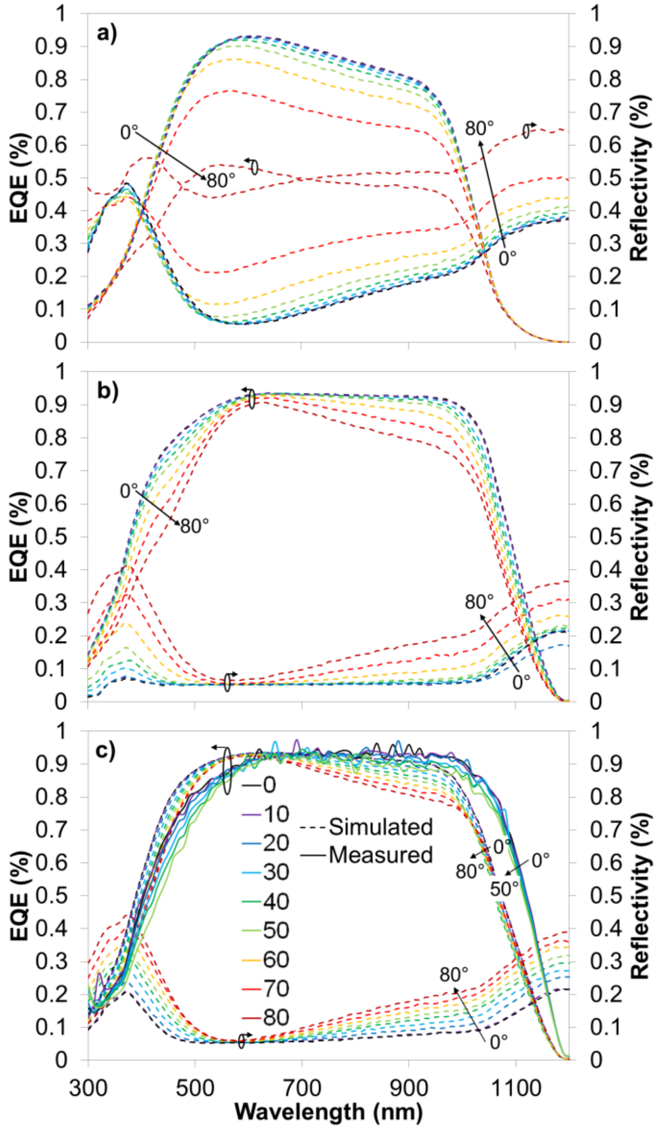

Fig. 2. External quantum efficiency and reflectivity for a solar cell with a) planar, b) random 70°, 1-µm tall cones, c) 52° 5-µm tall random upright pyramids for angles of incidence from 10° to 80° (pictured in varying color). Measured EQE is given by solid lines.

the measured solar cell exhibits greater absorption in the IR than the simulated cell, possibly due to scattering effects or reduced parasitic absorption in the ITO layers.

In the UV range, parasitic absorption in a-Si:H layers and the front ITO cause the most optical loss, while absorption in the rear ITO and transmission through the cell cause loss in the IR. This indicates that differences between the modelled and actual ITO may be the cause of EQE mismatch, due to decreased ITO absorption in the modelled cell.

While in practice, carrier collection can occur due to absorption in the a-Si:H films, SunSolve^{TM} considers all absorption in a-Si:H to be parasitic. In reality, the short diffusion length of carriers in a-Si:H results in a low collection probability. In our model, the highest EQE is obtained with the thinnest possible a-Si:H layers, since this reduces parasitic absorption. However, when it comes to layer thickness there is a tradeoff between optical losses and passivation quality of the silicon interface. For example, it has been shown that surface recombination velocities decrease dramatically to below 1 cm/s as a-Si:H layer thickness increases from 10 nm to 50 nm [3].

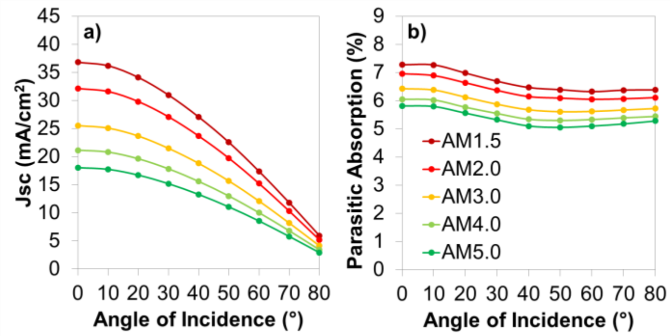

Fig. 3. Simulated (a) short-circuit current and (b) parasitic absorption in silicon heterojunction cell with varying air mass.

The effect of changing air mass on cell output was also studied, as shown in Figure 3. Spectra with increasing air mass were generated using SMARTS software and paired with SunSolve^{TM}. While the short-circuit current output decreases with increasing air mass due to reduced irradiance, the parasitic absorption as a fraction of the total incident power also decreases. This is primarily due to the decreased proportion of incident power in the UV.

SunSolve^{TM} does not simulate the effects of changing temperature, and so low-temperature simulations were not performed in this work. A model is underway in Synopsys Sentaurus TCAD that will allow for more rigorous optoelectronic modelling of bifacial SHJ cells.

IV. Summary

The performance of bifacial silicon heterojunction solar cells has been studied for angles of incidence up to 80°. Reflectivity had the highest impact on EQE with changing angle, highlighting the best anti-reflection treatments for a wide range of angles for northern deployments.

This optimization of bifacial SHJ solar cells for Arctic operating conditions will aid in the fabrication of bifacial solar panels enhanced for high-latitude deployment.

References

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