Assessment of Photovoltaic Surface Texturing on Transmittance Effects and Glint/Glare Impacts
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Outline

- Background
- Motivation for this work
- Approach
- Results and Discussion
- Conclusion & future work
Background – PV Module Construction

www.solarquotes.com.au
Background (2/2) – Reflections

1. Solar glint/glare from PV modules is caused by reflections off PV glass covers – minimize this.

2. Maximizing transmittance through cover glass to solar cells can increase energy production.
Surface Roughness Measurements Process

1. Prepare & clean the PV panel to be replicated

2. Replicate the PV panel surface with a 2-part rubber compound

3. Measure the small replica with an optical profilometer

4. Analyze the measured surface data to get the surface statistics
Surface Roughness Measurement Data

**Float Glass (Smooth)**
- $S_a = 0.06 \, \mu m$, $S_q = 0.10 \, \mu m$
- $S_z = 2.71 \, \mu m$, $\Lambda = 1.26 \, mm$

(b)

**Deeply Textured Surface**
- $S_a = 16.61 \, \mu m$, $S_q = 20.03 \, \mu m$
- $S_z = 95.56 \, \mu m$, $\Lambda = 0.77 \, mm$

**Lightly Textured Surface 1**
- $S_a = 1.44 \, \mu m$, $S_q = 1.88 \, \mu m$
- $S_z = 15.25 \, \mu m$, $\Lambda = 0.69 \, mm$

(a)

**Lightly Textured Surface 2**
- $S_a = 1.25 \, \mu m$, $S_q = 1.58 \, \mu m$
- $S_z = 11.88 \, \mu m$, $\Lambda = 1.36 \, mm$

(b)
Reflectance Measurements

**Final Corrected Photovoltaic Reflectance Data**

- light_mono_white_silver_200
- light_mono_white_silver_240
- smooth_poly_white_silver_220
- light_mono_white_none
- deep_mono_white_none
- AR_light_mono_white_none
- smooth_mono_white_none
- light_poly_white_black_230
- light_poly_white_black_240
- light_poly_white_black_225
- light_poly_white_black_225
- light_poly_white_silver_230
- light_poly_white_silver_240
- light_poly_white_silver_240
- AR_smooth_poly_black_black_235
- AR_smooth_poly_black_black_240
- smooth_poly_black_black_235
- smooth_poly_white_silver_240
- light_thin_black_black_40
- smooth_poly_white_silver_228
- smooth_mono_white_black_238
- smooth_mono_white_black_305
- AR_smooth_mono_white_black_318
- AR_smooth_mono_white_black_327
Reflected Solar Beam Spread Measurements

Smooth (float) glass, Lightly textured glass, Deeply textured glass

Samples courtesy of Canadian Solar, Inc.
Beam Spread Calculations

Beam spread at $1\sigma = 27.3$ mrad

 Beam spread at $1\sigma = 27.8$ mrad
Results on Surface Roughness & Beam Spread

Beam Spread, $\beta$ (mrad)

$S_q$ (\(\mu m\)) / $\Lambda$ (mm)

$y = 84.82x^{0.56}$

$R^2 = 0.93$
Ocular Hazards Study

Irradiance on the retina:
\[ E_r = \left( \frac{\rho E_{DNI}}{\beta^2} \right) \left( \frac{d_p^2 \tau}{f^2} \right) \]

Irradiance threshold for after-image potential:
\[ E_{r,\text{flash}} = \frac{3.59 \times 10^{-5}}{\omega^{1.77}} \]
Ocular Impacts From PV Surface Texturing

\[ E_r < E_{r,\text{flash}} \]

\[ \beta(\rho) > \left( \frac{\rho E_{DNI} d_p^2 \tau}{f^2 3.59 \times 10^{-5}} \right)^{\frac{1}{0.23}} \]
Example of PV Cover Glass Design

[Graph showing reflected beam spread vs. reflectance, and beam spread vs. $S_q (\mu m) / \Lambda (mm)$ with equations $y = 84.82x^{0.56}$ and $R^2 = 0.93$.]
Conclusions & Future Work

- Measured reflectance, surface roughness, and solar beam spread from several PV modules
- We attempted to correlate the beam spread to the surface roughness
- Developed a design method to minimize glint/glare from PV modules and maximize transmittance
- Results were incorporated in the SGHAT code

- Would like to study soiling effects on textured surfaces
- Build engineered surface texturing for PV and evaluate
Extra Slides
# Replication Accuracy & Verification

<table>
<thead>
<tr>
<th>AVG Surface Roughness, $S_a$ (µm)</th>
<th>Master Avg. Measurement</th>
<th>Replica Avg. Measurement</th>
<th>% Error</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.85 ± 0.18</td>
<td>2.00 ± 0.05</td>
<td>7.7</td>
<td></td>
</tr>
<tr>
<td>RMS Surface Roughness, $S_q$ (µm RMS)</td>
<td>2.45 ± 0.24</td>
<td>2.61 ± 0.13</td>
<td>6.6</td>
</tr>
</tbody>
</table>
Slope Error Calculation From Glare Measurements

• The angular beam spread after reflection is defined as:

\[ \sigma_{\text{BeamSpread}} = \sigma_{\text{Sun}} + \sigma_{\text{Total_SlopeError}} \]

– where the Sun subtended angle (\(\sigma_{\text{Sun}}\)) is about 9 mrad

• The ‘Total Slope Error’ quantity is a combination of the panel surface slope error and specularity due to surface texturing; it’s typically defined as:

\[ \sigma_{\text{Total_SlopeError}} = \sqrt{4\sigma_{\text{SE}}^2 + \sigma_{\text{Sp}}^2} \]

– where \(\sigma_{\text{SE}}\) is from the surface slope errors, and \(\sigma_{\text{Sp}}\) is the specularity from the surface texturing (i.e. surface roughness); the factor of 4 is because the surface slope errors are measured at the surface, whereas the specularity is measured at the reflected beam – note that with a single glare measurement, these two quantities are difficult to decouple.

Note that \(\sigma\) can be one-sided or two-sided. In this analysis, a two-sided \(\sigma\) is used, which gives the full beam spread.