Combining Laser Texturing and Wet Chemical Etching for Anti-Glare Properties of Photovoltaic Module Glass

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We report on a process for fabricating anti-glare surface textures for PV module glass using a hybrid approach that combines laser texturing and wet chemical etching. This texture scatters reflected light and thus significantly reduces glare. In addition, the textured surfaces exhibit a reduction in total reflectance, which is particularly pronounced at high angles of incidence, compared to an untreated glass surface. The combination of these two properties is highly desirable for the integration and acceptance of PV in urban environments such as BIPV.

Motivation and Process Description

- Planar and uncoated PV module glass surfaces exhibit a reflectance of approximately 4 % under normal illumination [1], which leads to energy loss in a PV module and results in a significant degree of glare.
- Our goal is to:
  a. Reduce **glare** by scattering the specular reflection
  b. Reduce total direct-hemispherical **reflectance**
- Both aspects are already addressed industrially by applying a texture or a coating to the front surface of the module glass.
- We present a maskless, hybrid texturing process that involves a fs-laser structuring step (a) and subsequent wet chemical etching using a hydrofluoric acid solution (b).

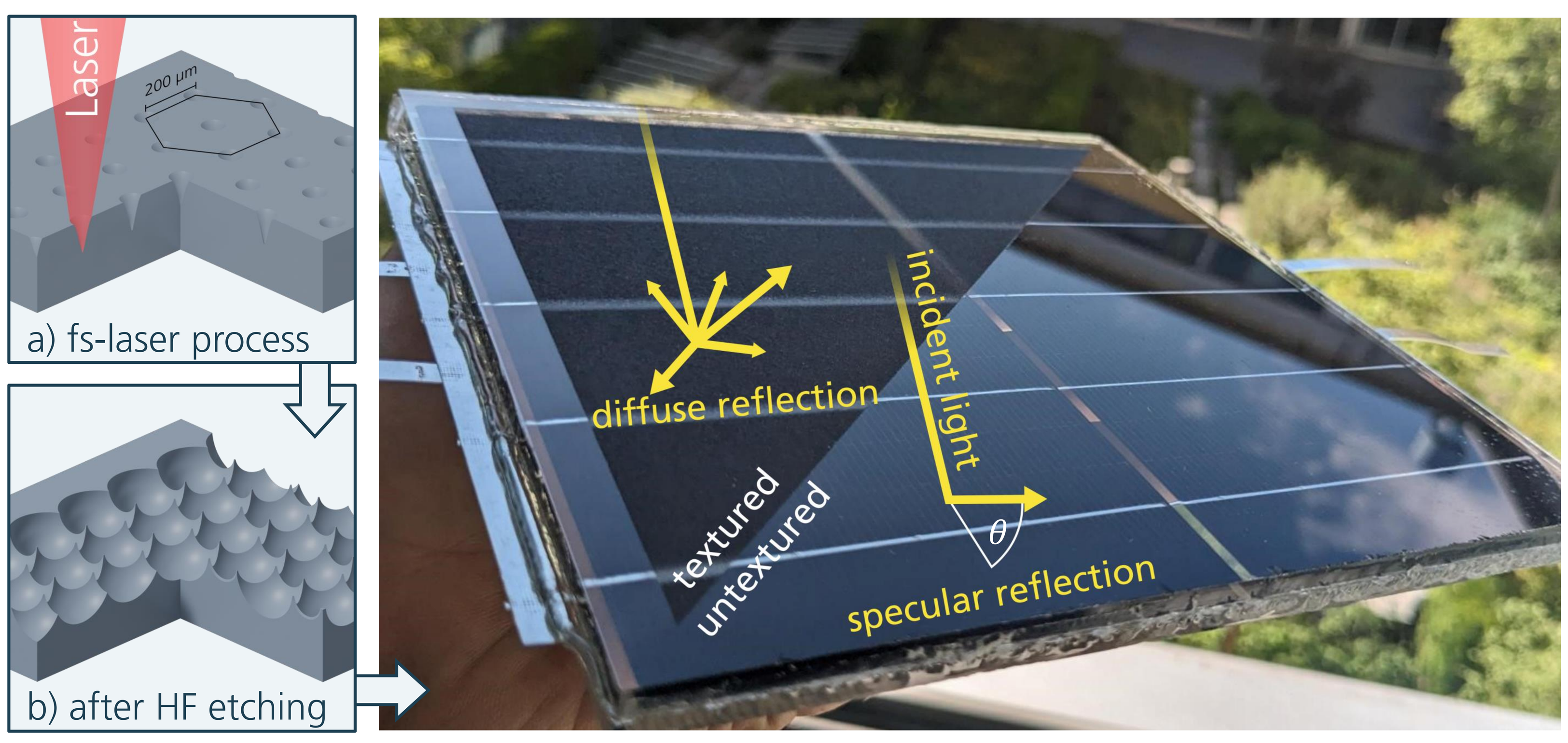
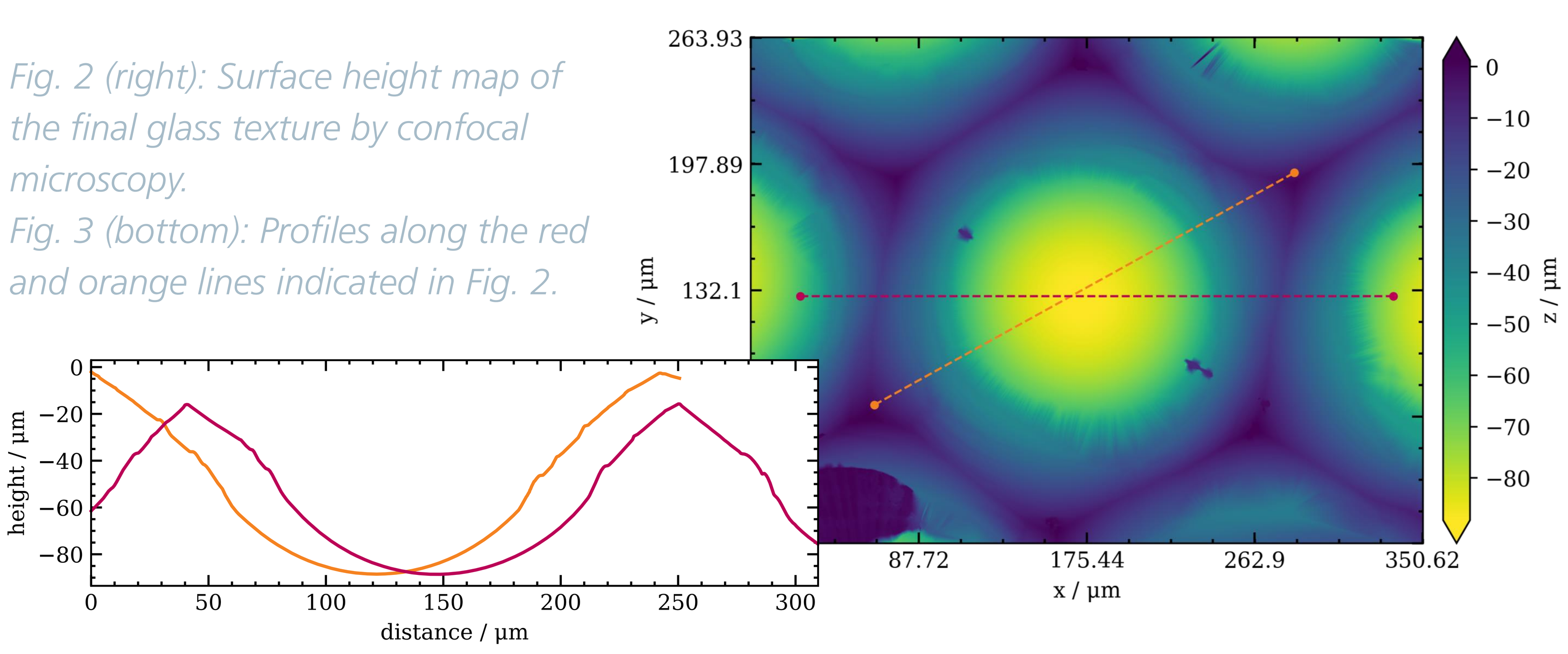


Fig. 1: Process flow (left) and photo of a single-cell module with a half-textured cover glass (right). The untextured side shows specular reflection, while no reflection image is visible on the textured side.

Geometric Properties of the Texture

Fig. 2 (right): Surface height map of the final glass texture by confocal microscopy.
Fig. 3 (bottom): Profiles along the red and orange lines indicated in Fig. 2.



Optical Characterization Results

The optical properties of the textured glass sample are characterized using bidirectional reflectance distribution function (BRDF) measurements.

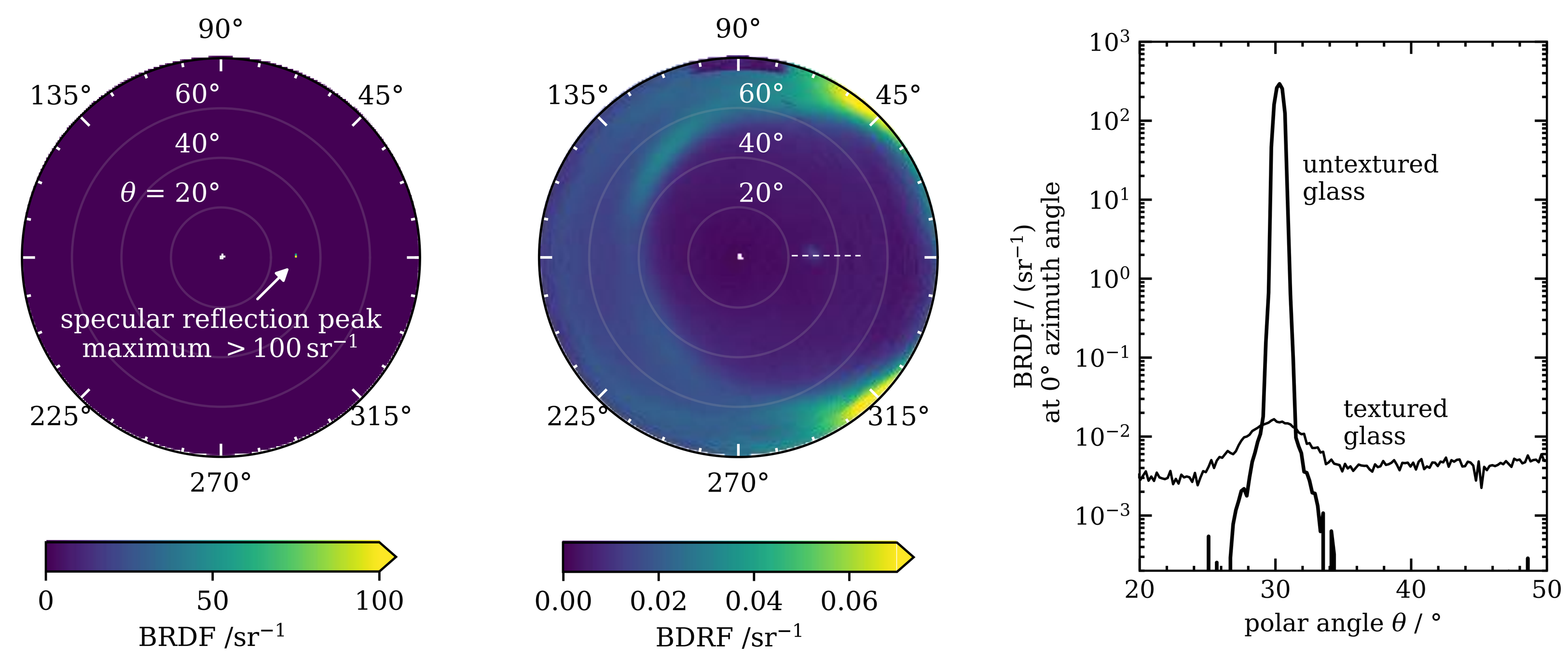


Fig. 4: The BRDF of the untextured surfaces (left) shows a significantly higher and narrower reflectance peak than the BRDF of the textured surfaces (center). The profiles through the specular reflectance peaks (right) show the difference in amplitude.

The **glare** is assessed by determining the amplitude of the specular reflectance peak. For the textured glass, the reflectance amplitude is reduced by a factor of > 1000 and the reflected light is scattered over a wide solid angle.

- For low angles of incidence, the **reflectance** is reduced by ≈ 40 %, compared to untextured glass.
- The decrease is more pronounced for shallow incident angles > 45 °.
- Similar results are obtained by using a path tracing simulation.
- Modern anti-reflective coatings (ARCs) still outperform our texture in terms of improving module efficiency [2].

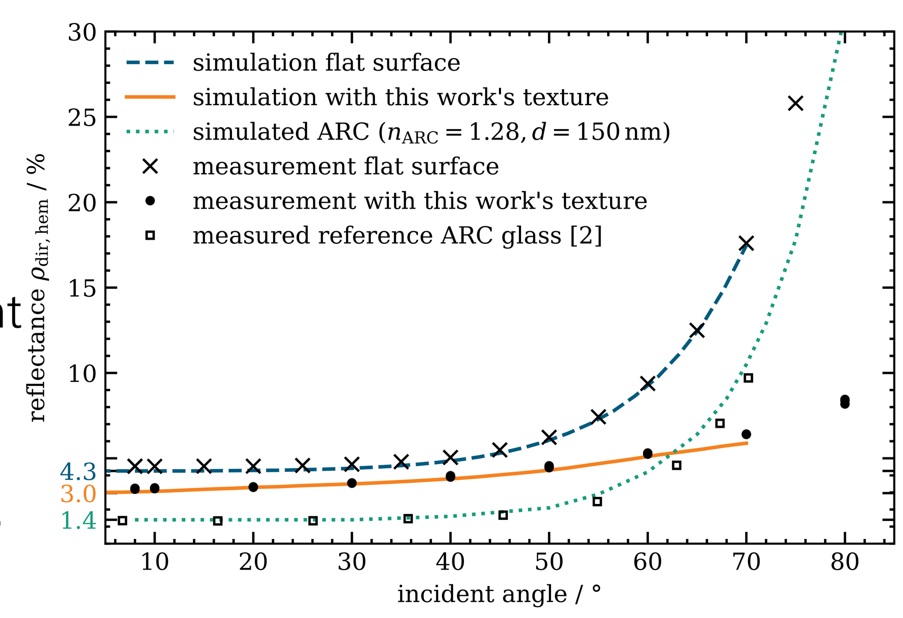


Fig. 5: Direct-hemispherical reflectance as a function of the light incident angle.

Optimizing the Process Throughput

- Using a prototyping process, we are able to produce samples of up to 150 × 150 mm² in approximately 40 minutes.
- We are currently investigating the use of high power lasers, interference optics (DLIP), diffractive optics and polygon scanners for process acceleration.

Conclusion and Outlook

We have demonstrated an etching assisted laser machining process for fabricating anti-glare surface textures on PV module glass, which have shown effective anti-glare properties while reducing the reflection losses by ≈ 40 %, thereby increasing module efficiency. We are investigating methods to accelerate the process and expect to achieve industrially relevant throughput.

[1] B. M. Freiburger, C. S. Thompson, R. A. Fleming, D.Hutchings, and S. C. Pop, Eds., *High Efficiency Anti-Reflective Coating for PV Module Glass*, 2017 IEEE 44th Photovoltaic Specialist Conference (PVSC) (Washington, DC, USA), 2017, 4 pp.
[2] DSM Advanced Surfaces, *Same sun, more power, KhepriCoat TM – the best-performing anti-reflective coating for solar cover glass*, 2011

link to Fraunhofer ISE contributions of the 40th EU PVSEC, available as of 20.09.2023

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