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ANTI-GLARE BIFACIAL MODULE DESIGNS WITH STRUCTURED GLASS FOR FAÇADE APPLICATION

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ABSTRACT: Façades of buildings can be an important part of the upcoming energy system if photovoltaic (PV) modules are installed. In this context, we propose the integration of PV module lamellae mounted perpendicularly to the original façade optimizing the compromise between PV yield, shading and interior lighting of the building. Mitigating glare caused by sun reflection on the cover glass of a PV module is of paramount importance to ensure the effective operation of a PV system integrated into façades. This is achieved by glass surface structuring using laser processing in combination with wet chemical treatment. Bidirectional reflectance distribution function (BRDF) measurements revealed a reduction by more than three orders of magnitude for the treated glass surface.

Keywords: Building-integrated photovoltaics, glass structuring, laser, wet etching

1 INTRODUCTION

Mankind has already occupied large portions of earth's surface and built streets, buildings, parking lots, etc.. To omit further negative impact on nature (biodiversity, water management, …), the multifunctional use of already sealed surfaces is wise. Roof areas are more and more not only a protective skin of the building's inside anymore but also produce electricity by photovoltaic module integration. It was shown that façades of buildings can also provide significant amounts of electricity by implementing PV modules [1]. However, among others, one has to take care of a few aspects:

- Find architectural appealing and aesthetic design opportunities.
- Find a concept that allows applicable cost structures for a widespread application.
- Omit glare/ reflection effects that could create limited sight during passing (e.g., driving) by or could reduce life quality inside or outside the house.
- Find a good compromise between electricity generation by PV and illumination of the living/working space inside adjacent houses.

Additional aspects include electrotechnical, mechanical, and legal topics.

Currently, the mass market for PV module producers does not take façade applications into account. Besides façades, also other perpendicular structures like noise protection walls along highways or similar are relevant examples for the application of such modules. According to an estimation of Eggers et al. [1], one could install – with current PV module technology efficiencies – about 400 GW_P of PV power at existing German façades of buildings with a minimum of 500 kWh/m^2/a of solar illumination. Using a significant part of this potential would provide an important share of the needed PV power capacity in the German grid. Our developments of anti-glare bifacial module technologies help to overcome hurdles in using these potentials.

In this work, we present innovative façade design concepts that combine PV lamellae with structured glass to achieve a harmonious blend of high electrical performance, abundant natural lighting inside the building, and comfortable shading to protect occupants from excessive heat and glare. The structured glass is realized through a two-step approach combining laser irradiation and a subsequent wet chemical treatment.

2 MOTIVATION / APPLICATION CASE

Façades show a huge potential for PV integration, allowing for a significant share of the needed PV integration in existing buildings to meet the electricity needs of our societies. Thus, good concepts for the transformation of passive into electricity generating façades are very useful now and in the future.

In Figure 1, façade sketches are shown with perpendicular thin PV modules placed in front of a freely designable glass window/concrete/wood/steel/ or other type of wall. The PV modules (lamellae) have a front and a back side, each absorbing light and generating electricity (bifacial solar cells and modules). The lamellae can be placed near to each other resulting in greater shading of the building's inside (i.e., cooling effect in summer and less blinding by direct sunlight). A larger distance between the lamellae would allow a clearer view from inside the building to the outside. More lamellae would obviously typically lead to higher cost of the structure.

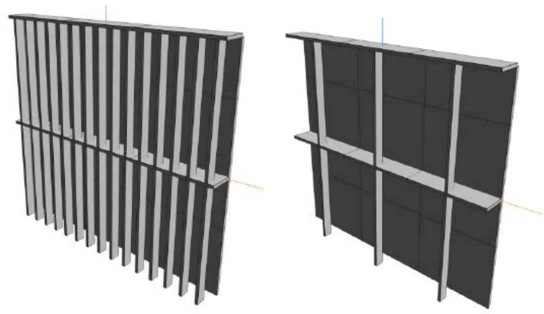

Figure 1: Sketches of façades with differently distanced perpendicularly arranged lean PV modules (lamellae).

Preliminary simulations were performed with a similar context to investigate the electricity generation potential of such installations. Here, the case of a façade facing south with the lamellae facing east and west is considered. Figure 2 shows the results of the simulation. The upper image shows a false colour image of an exemplary design and visualizes the sum of the light hitting either side of the lamella over the course of a year – up to 1000 kWh/m2/a of illumination can be achieved. However, the light energy is not equally distributed onto the lamella surface portions. Closer to the inner building and going higher towards the horizontal stabilizing part, the amount of light is decreasing due to shading of the supporting structure.

Thus, a smart module concept would be beneficial for the electricity output.
Additionally, in case the lamellae would be made with flat glass on the outside, light reflection effects would be an important drawback of the integration of such installations into a façade. Thus, a technically viable way to reduce glare very effectively is essential. It would allow a naturally illuminated living and working area inside the building without glare-depending disturbance and without the need of sun-blinds for most of the daytime.

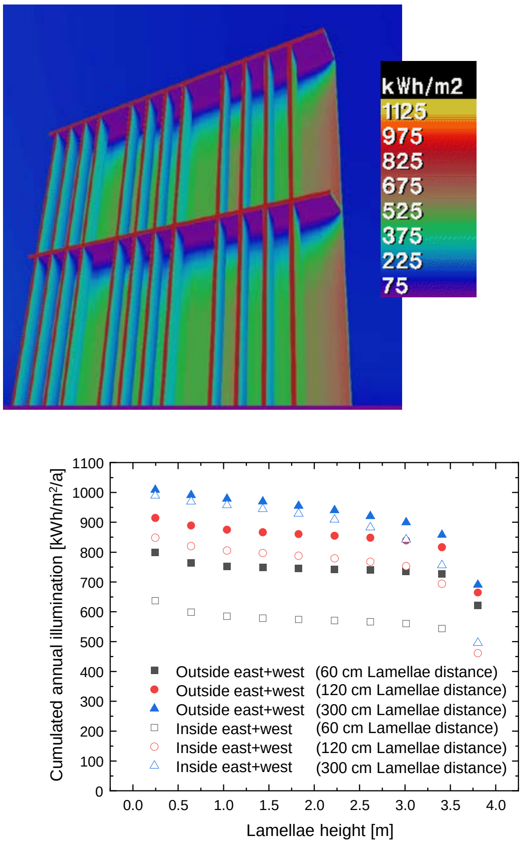

Figure 2: *Top:* Simulation results showing the cumulated annular light energy hitting different surface portions of a façade with differently spaced perpendicular PV lamellae in Germany.
Bottom: Simulated cumulated annual light energy hitting front and back of a PV lamella in Germany. The amount of light is depending on the distance of the lamellae and on the height position on the lamella since shading occurs due to horizontal elements in the simulated case.

3 STRUCTURING OF GLASS

In our research, we have learned that a significant degree of freedom in altering the size and shape of structure features on the glass surfaces can be achieved by a two-step process which combines a laser pre-process and a wet chemical post-process. The laser process prepares the glass surface in such a way that wet chemical etching for example results in very steep features. In Figure 3 and Figure 4, exemplary measurement results of such treated glass surfaces are presented. Figure 5 shows an example of a glass sample that was partly treated by a laser and wet etching process sequence.

Please refer to a paper of L. Bienkowski et al. on this topic which will be submitted shortly [2].

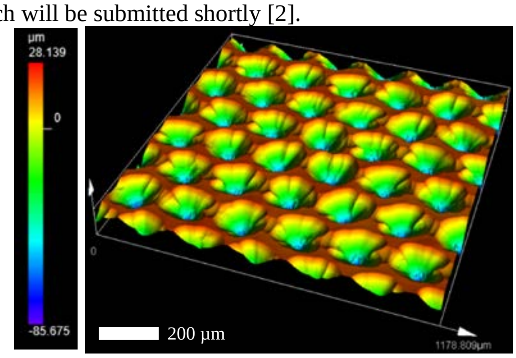

Figure 3: Glass surfaces were treated in a two-step process sequence using laser processing and wet chemical etching. An exemplary false-color image of the height profile of a periodic structure measured applying confocal microscopy is shown.

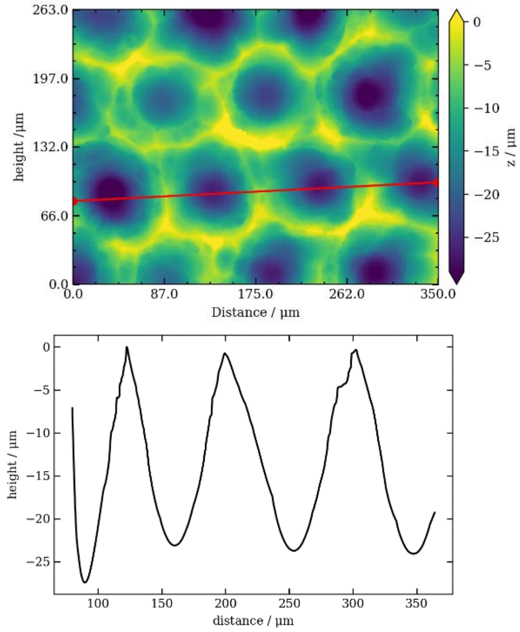

Figure 4: Confocal microscopy results: top: false-color height profile, bottom: line scan result following the red line in the top image. Surface scan results show steep structures at the glass surface for a process with periodically distributed laser spots. This presents another process example, not directly comparable to Figure 3.

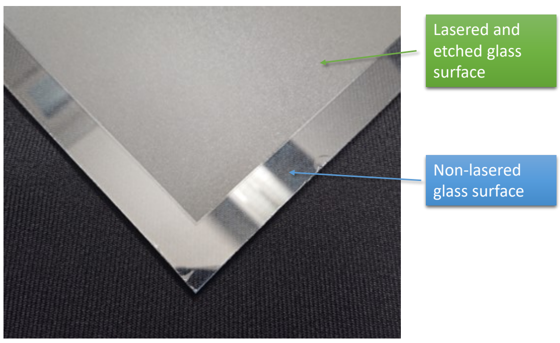

Figure 5: Photo of an exemplary glass sample with a portion of its surface sequentially lasered and etched. Along the edge of the sample, non-lasered areas are visible and can be used as visual reference.

Mapping a larger portion of such a treated glass surface by confocal microscopy and plotting the first derivative of the resulting data as a slope angle histogram resulted in Figure 6.

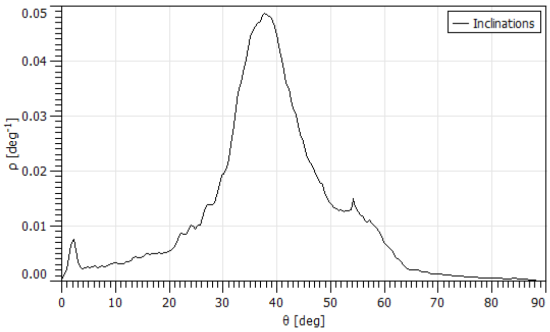

Figure 6: This histogram of the surface angle distribution of the treated glass sample shows a steep and widely distributed structure with the peak of distribution in the range 35-40°.

4 ANTI-GLARE EFFECT

In order to reduce the luminance of the sunlight reflected from the surface to such an extent that glare no longer occurs, a strongly diffuse reflection behavior is aimed for. One measure of this is the surface angle distribution: the wider the surface angle distribution, the more diffuse the reflection behavior. Figure 6 shows a wide surface angle distribution.

For a better quantification, the luminance of the reflected sun light was estimated for an incidence angle of the sun of 10° based on the surface angle distribution. When comparing a non-treated flat glass showing a luminance of more than 300,000 cd/m^2 to the lasered and etched sample presented above with less than 5,000 cd/m^2, we see that a large reduction of luminance can be achieved while still keeping the transmission through the glass (and towards the solar cells) high.

The angle-dependent reflection behavior of a material is described by its Bidirectional Reflectance Distribution Function (BRDF). It is defined as the quotient between the radiance of the incident light and the reflected irradiance as a four-dimensional function over the angle of incidence and reflection. Figure 7 shows the BRDF of an untreated glass (top) and the lasered and etched glass (bottom) measured with a 3D scanning goniophotometer (PG II Gonio-Photometer, pab advanced technologies Ltd, Freiburg, Germany). The untreated glass shows a sharp peak and thus a strong specular reflection. In comparison, the lasered and etched glass reflects light diffusely over a wide solid angle.

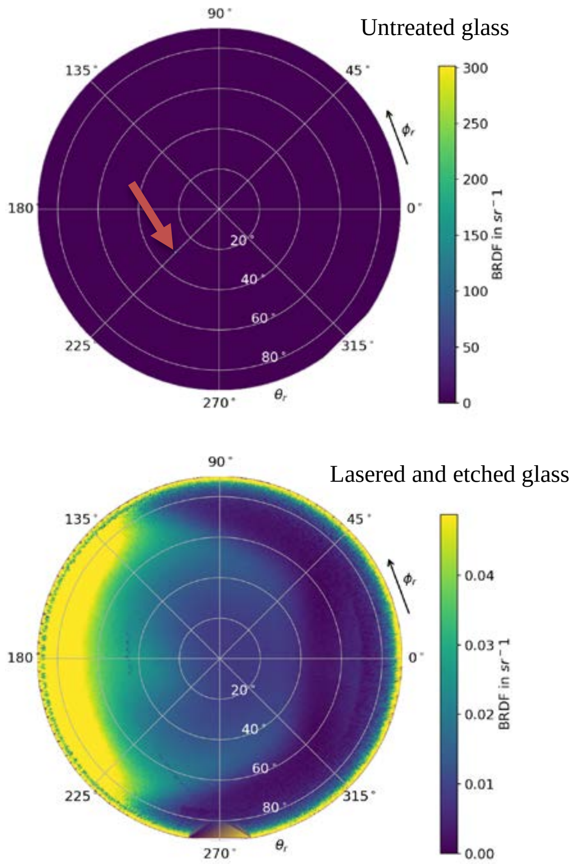

Figure 7: Bidirectional reflectance distribution functions (BRDF) for a polar angle of incidence of 30° and an azimuthal angle of incidence of 0°.

Top: Untreated glass showing a very high peak at the direct reflection angle of 30°. The red arrow points at the small but very bright dot that represents the reflection position.

Bottom: BRDF of a lasered and wet etched glass sample with very low BRDF value range showing a large distribution of the reflected light (large scattering).

Please note that the color scale differs by almost 4 orders of magnitude.

5 STUDY ON GLARE ASSESSMENT

Glare can be dangerous and/or life quality decreasing in different situations. One very important segment influenced by glare is the mobility sector. We plan to perform studies on the assessment of glare in the case of driving in a car and passing by glare effects. Two study parts are currently under preparation, a first investigation will look at different lighting and glare situations in a lab environment. In a second step, field tests will be performed. The studies shall also help to generate a proposal for standardization work and will also take the pre-work of Fraunhofer ISE into account [3-6].

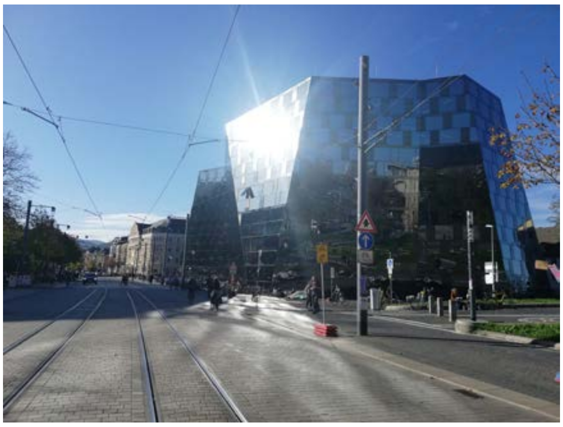

Figure 8: Example for a glare situation (new library of the university of Freiburg); image is courtesy of Fraunhofer ISE, taken from the website bipv-bw.de

8 SUMMARY

Structuring of glass surfaces with the combination of laser treatment and a subsequent wet etching process offers a large variety of surface morphologies. The creation of structures that lead to large scattering of reflected light resulting in a strong suppression of glare was possible and presented. This helps to outline technological paths for a large application of PV also for facades, noise barriers, etc.

Acknowledgements

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