Sun-Light Harvesting with Surface Patterned Glass for Photovoltaics

Andreas Nositschka
Herzogenrath R&D Centre
Saint-Gobain Sekurit Deutschland GmbH&Co.KG
Motivation
Functionality of textured glass
SGG ALBARINO P and G
measurement of textured glasses
PV results
  • Solar simulator
  • Outdoor testing
  • Soiling
conclusion
Efficiency Improvements: Principle

Aim: Improve photovoltaic module performance
Minimizing Reflection Losses

glass surfaces with steep surface **texture**
- light-trapping
  - particularly effective for non-textured solar cells

glass with an anti-reflection **coating**
- eliminating reflection
  - effective for textured high-efficiency solar cells
Efficiency Improvements: added value

- assumption: 2€/Wp, 100-150Wp /m^2
- ARC or textured glass: 2-3% relative higher efficiency
  - added power: 2-4.5W/m^2
  - added value: 4-9€/m^2
- glass manufacturer makes a 50:50 deal with the module manufacturer
  - 2-4.5€/m^2
Minimizing Reflection Losses

glass surfaces with steep surface texture

light-trapping

→ particularly effective for non-textured solar cells
SGG Albarino® P and -G

Inverted Pyramids (SGG Albarino P)
Best light-trapping

Grooves (SGG Albarino G)
less sensitive to surface dust
SGG Albarino® P and –G: current products

“randomized” pyramids
(SGG Albarino P)

curved grooves
(SGG Albarino G)
SGGAlbarino P: Principle @ high angles of incidence

- Efficiency increase is due to reduction of the angle of incidence (in the example R=13%@65°, R=4%@20°)
- No light trapping is possible for these angles
SGGAlbarino P: Principle @ high angles of incidence

1. “Antireflective” effect: lower reflection for flat angles

For a texture: -45°<β<45° for α=45°

Reflection properties for a plane surface

Working domain with textured glass for external reflection
2. “Light-trapping” effect: **double reflection (A) at front surface** and **total internal reflection at glass-air interface (B)**
patent situation deep textures for light-trapping

SGG has filed different patents in that filed to protect the ideas of Albarino P and G

- so far granted patent in USA and EU (US7368655B2)
- Other patent granting ongoing
Production of Albarino
The real texture

How does it look like?

Albarino P so far is an inverse (negative) and Albarino G a “positive” pattern.

Pictures by Michele Schiavoni & Patrick Gayout, SGR
Efficiency increase is due to light trapping (2 reflections too loose a light ray)

In real Albarino P light trapping cannot take place for some positions on the glass cover
Reduction of Reflection at **Air/Glass** and **Glass/Si** interface

effect: double reflection (A) at front surface and internal reflection at glass-air interface (B)
Problem to measure SGG Albarino-P or Albarino-G: method to measure the glass transmission fails with structured glass

Light does not arrive at the detector
current instead transmission

making minimodules (e.g. 1 cell) to compare flat and structured glass

- first measure cells to get correction factor
- make 2 modules: one with flat, one with structured glass
- measure directly neighboured or directly one after the other under solar flasher
Measuring the Current increase

- textured x-white glass
- non-textured x-white glass
- variation of solar cell angle
“normal” texture of patterned glass as face 1?

advertised by some glass manufacturers
sometimes believed by PV manufacturers!
Albarino´P (randomised pyramids)

- good efficiency enhancement

Gain of Albarino-P compared to Albarino-S

\[
\text{gain} = \left[ \frac{(I_{sc, \text{textured}} / I_{sc, \text{ref}})}{1} \right] \times 100\%
\]
**Albarino G (curved chess board)**

- good efficiency enhancement measured in lab

\[
gain = \left( \frac{I_{sc, \text{textured}}}{I_{sc, \text{ref}}} \right) - 1 \right] \times 100\%
\]

**gain of structured glass compared to flat glass (Albarino S)**

- Albarino-G vs Albarino-S (non-textured solar cells)
- Albarino-G vs Albarino-S (textured solar cells)

![Graph showing the gain of structured glass compared to flat glass (Albarino S).](image)
Albarino G

results published at EUPVSEC 2007*

outdoor tests at Sandia started
(2008 January)

A. M. Gabor et.al., TEXTURED GLASS AND ANTIREFLECTIVE-COATED GLASS FOR STRING RIBBON PV MODULES, 22nd EUPVSEC, 2007, p2728-2731
Testing outdoors of solar test modules

- oriented strictly to the south
- angles of incidence
  - Germany: 10°, 30°, 45°, 60°, 90°
  - Spain: 30°
- new test sites planned in Asia (Korea and China)

Testing

- PV module performance (measurement of short circuit current $I_{sc}$ (no power tracking))
- transmittance of glasses
- dust accumulation (by eye)
Outdoor testing in Herzogenrath Germany

- enlargement of test site in September – October 2006
- climate: mid latitude, maritime
Outdoor testing of Albarino-P during one year

Herzogenrath from September 2003 – April...October 2004 under 30 % angle of the facade, mean average 2.3 % efficiency increase

almost exclusively cloudy, only one late afternoon of direct sunlight

heavy excavation activity for 3 weeks next to modules

rain- and wind-induced self-cleaning

self-cleaning → only short-time dust accumulation
results outdoor test façade Germany

intraday performance

- broad gain in current over the whole day

- especially higher gain for flat angles of incidence:

  BIPV, winter time, morning and evening hours
results outdoor test facade Herzogenrath

current gains test facade 30° (08:00 - 17:00)

- Albarino G (acid textured cells)
- Albarino G (non-textured cells)
- Albarino P (acid textured cells)
- Albarino P (non-textured cells)

annual yield ~ 5%
outdoor testing in Almunia Spain

climate: sub-tropical, continental, dry summer

Undisturbed view to the south / sun over whole year
results outdoor test façade in Spain

current gains new test facade 30° (08:00 - 17:00)
results outdoor test façade in Spain

- dust accumulation (9 months period without any rain!)

- flat untextured glass (Albarino T)

- textured glass (Albarino G)
Conclusions Albarino P and G

- Textured glasses increase the electricity yield of PV modules by light-trapping.
- Gain of efficiency (STC, module flasher) ~ 2-3%.
  - Different feedback from customers (not easy to measure).
- Very good outdoor long term performance.
  - Distinct higher gain outdoor than predicted by indoor (flasher) measurements.
  - Depending on weather and climate conditions, annual efficiency gain is ~5% in Germany and also in Spain.
  - No loss of efficiency gain through additional accumulation after > 2 years (respectively 18 months).
  - Especially higher gain for flat angles of incidence: BIPV, winter time, morning and evening hours.
  - First very positive feedback from customers in terms of soiling and kWh/kWp.
Let the sun shine through!

Thank you very much for your attention!