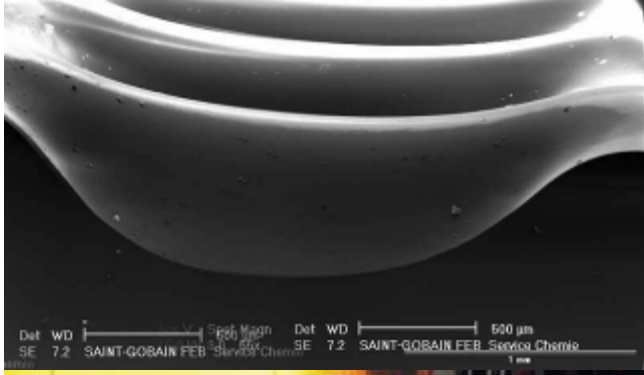
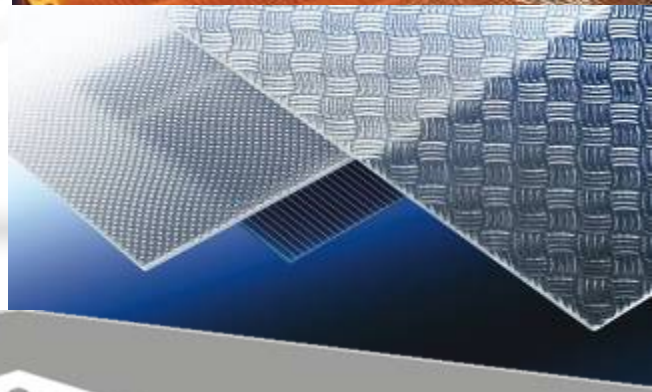
International Workshop on Glass for Harvesting, Storage and Efficient Usage of Solar Energy
Sunday, November 16, 2008 - Tuesday, November 18, 2008,
Pittsburgh, PA, USA





Sun-Light Harvesting with Surface Patterned Glass for Photovoltaics

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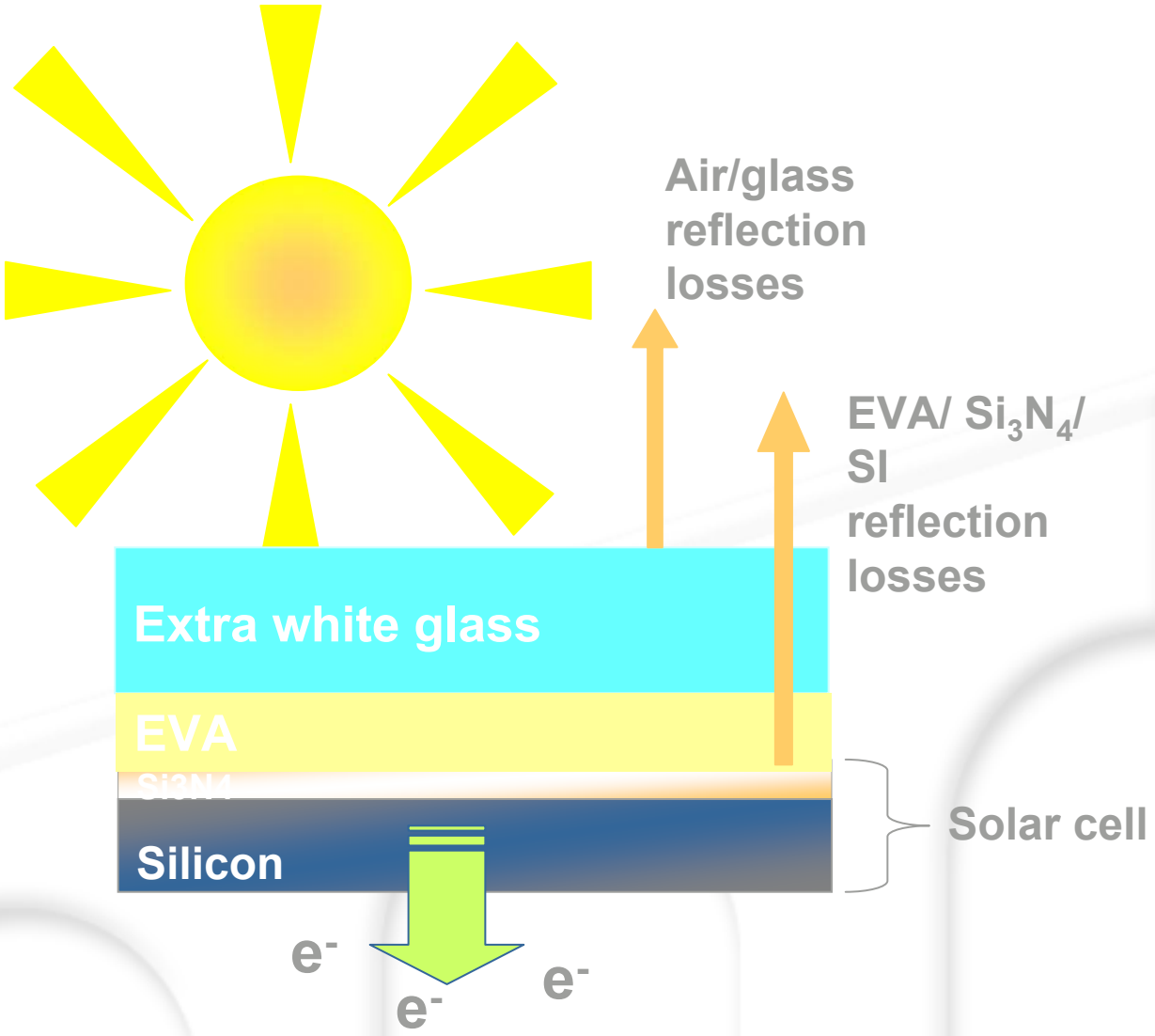
overview

- Motivation
- Functionality of textured glass
- SGGALBARINO P and G
- measurement of textured glasses
- PV results
  - Solar simulator
  - Outdoor testing
  - Soiling
- conclusion

Efficiency Improvements: Principle

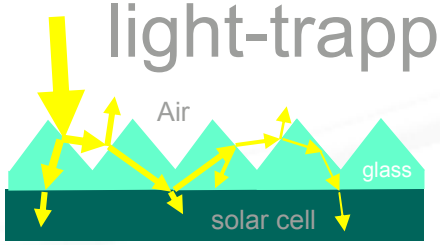
Aim: Improve photovoltaic module performance



Minimizing Reflection Losses

glass surfaces with steep surface **texture**

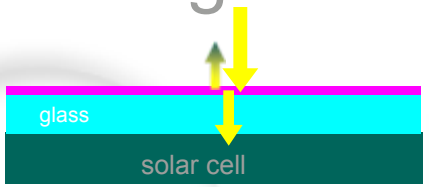
light-trapping



→ particularly effective for non-textured solar cells

glass with an anti-reflection **coating**

eliminating reflection



→ effective for textured high-efficiency solar cells

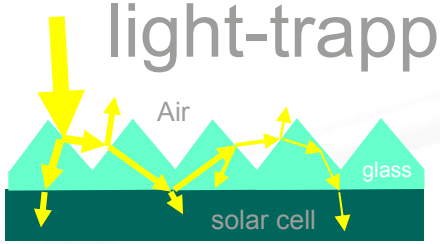
Efficiency Improvements: added value

- 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

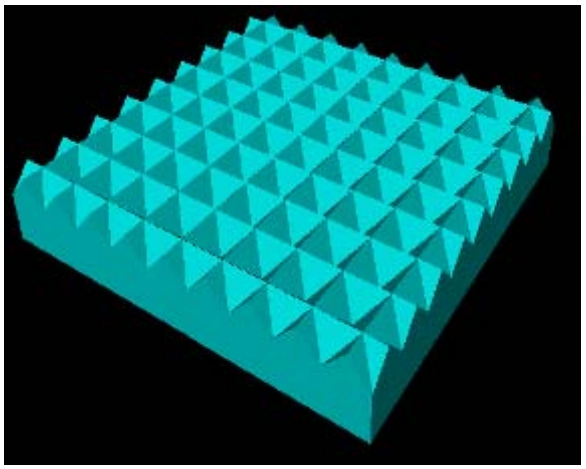
glass surfaces with steep surface **texture**

light-trapping



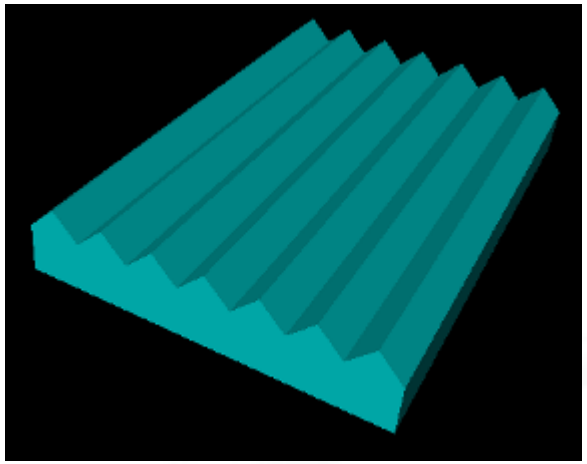
→ particularly effective for non-textured solar cells

SGG Albarino® P and -G



Inverted Pyramids
(SGG Albarino P)

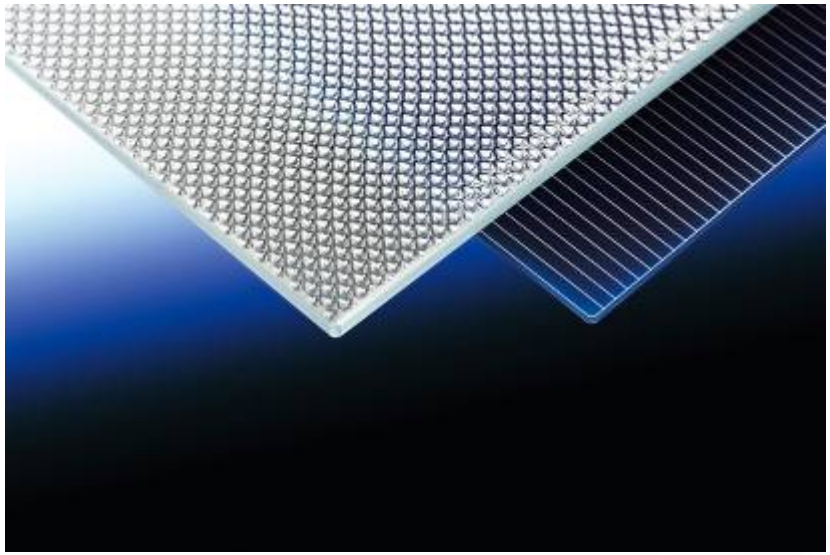
Best light-trapping



Grooves
(SGG Albarino G)

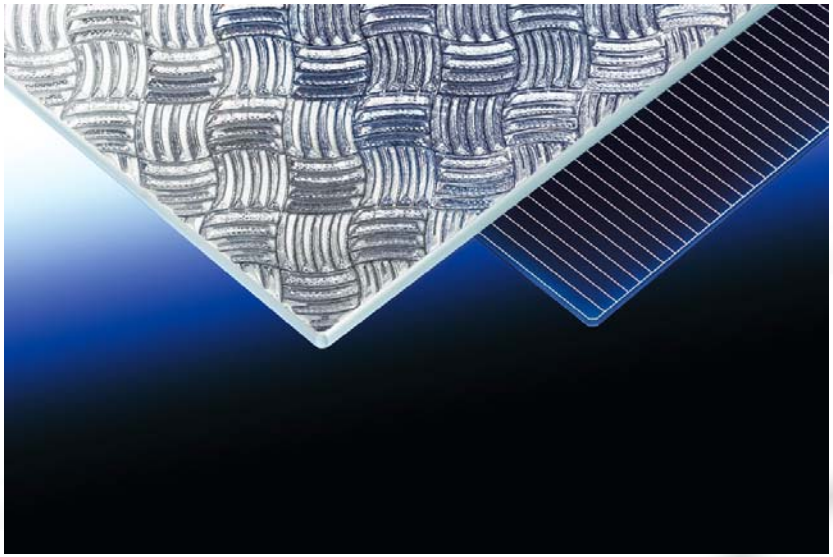
less sensitive
to surface dust

SGG Albarino® P and –G: current products



“randomized” pyramids

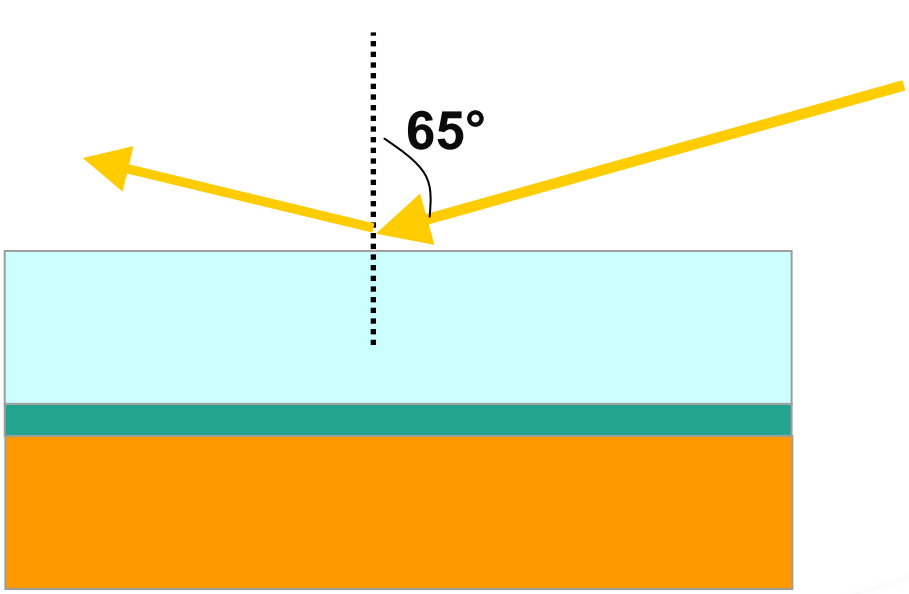
(SGG Albarino P)

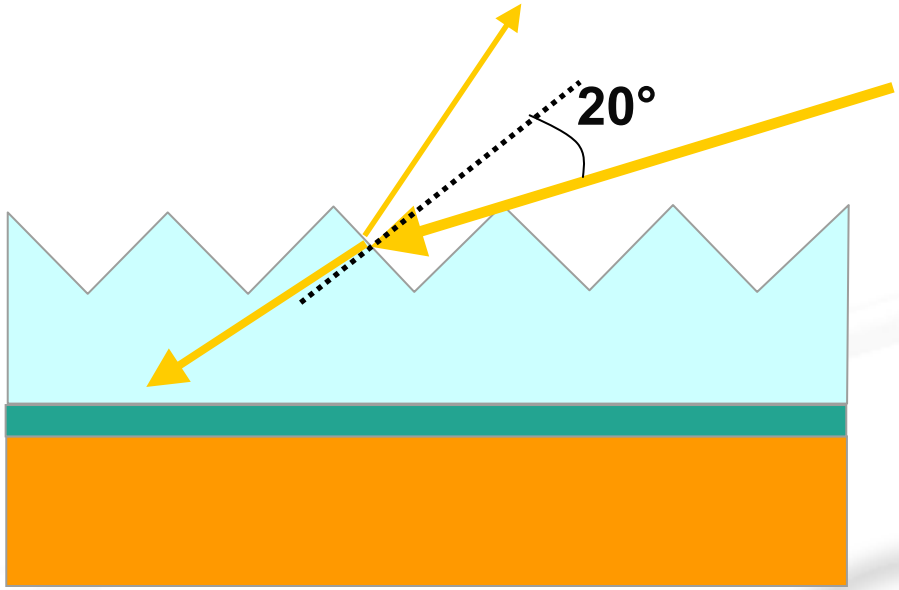


curved grooves

(SGG Albarino G)

SGGAlbarino P: Principle @ high angles of incidence



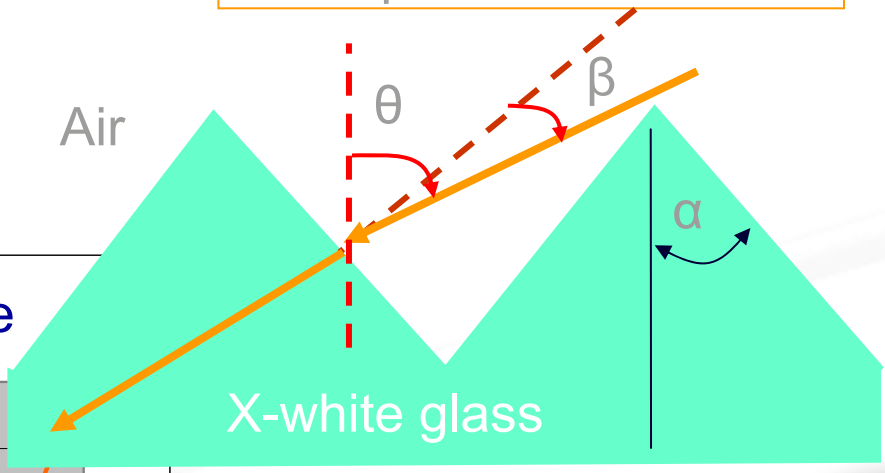


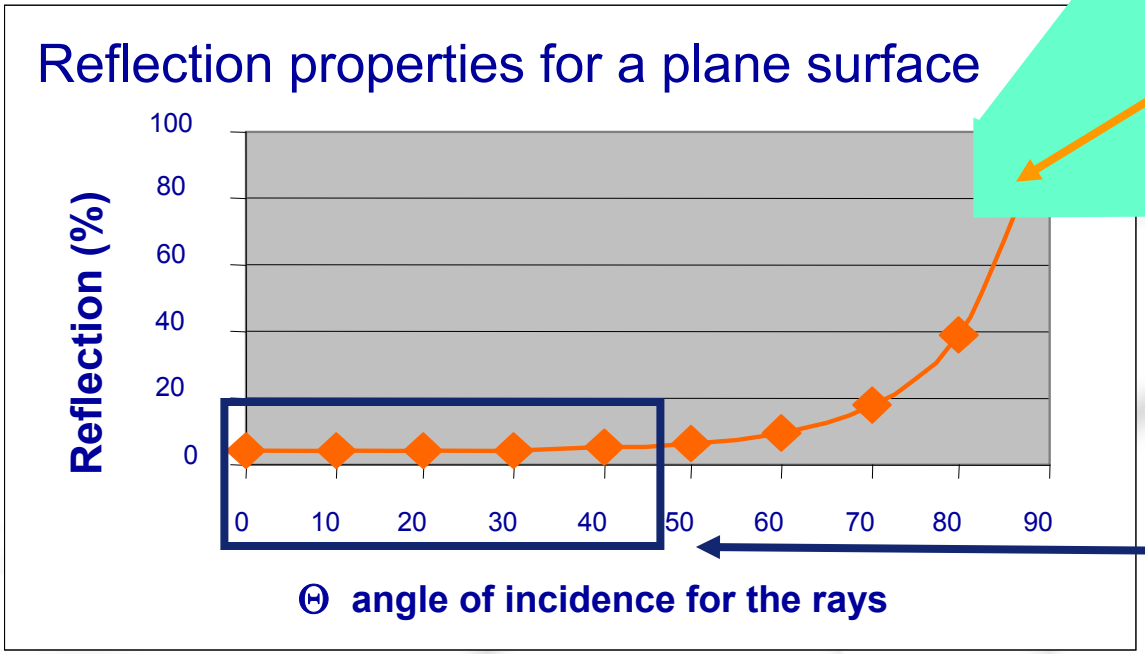
- Efficiency increase is due to reduction of the angle of incidence (in the example R=13%@65°, R=4%@20°)
- No light trapping is possible for these angles

SGGAlbarino P: Principle @ high angles of incidence

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

For a texture : - 45°<β< 45° for α =45°

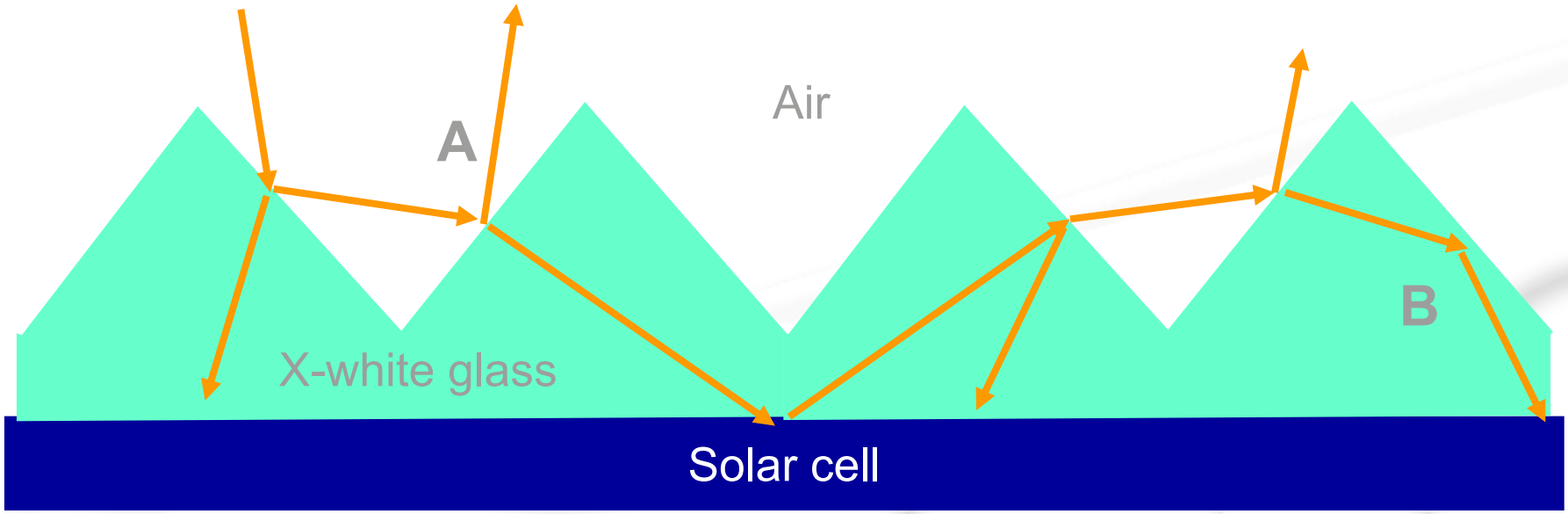




Working domain with textured glass for external reflection

SGGAlbarino P: Principle @ small angles of incidence

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 SGGAlbarino

furnace

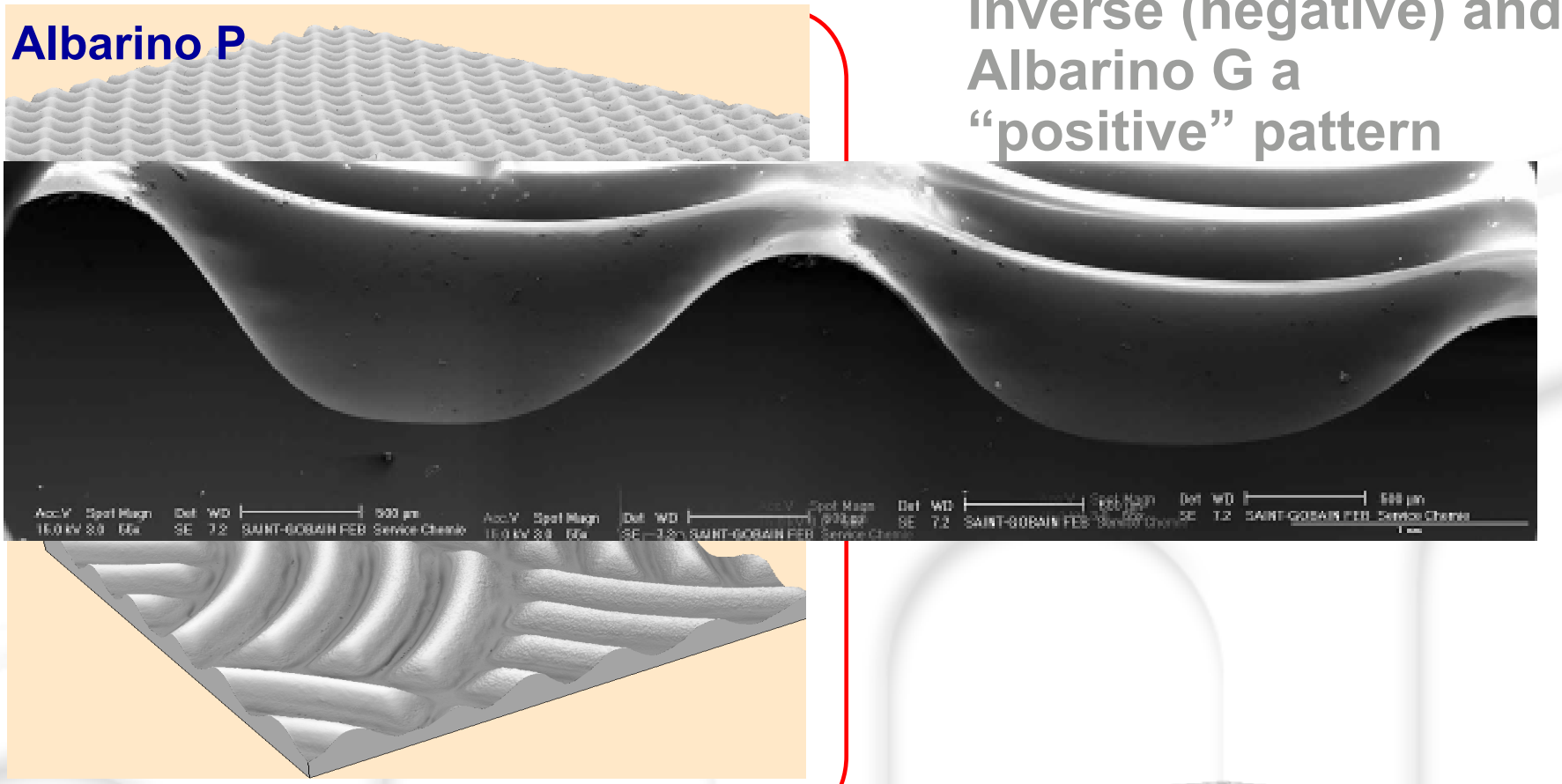
Cooling zone

cutting

The real texture

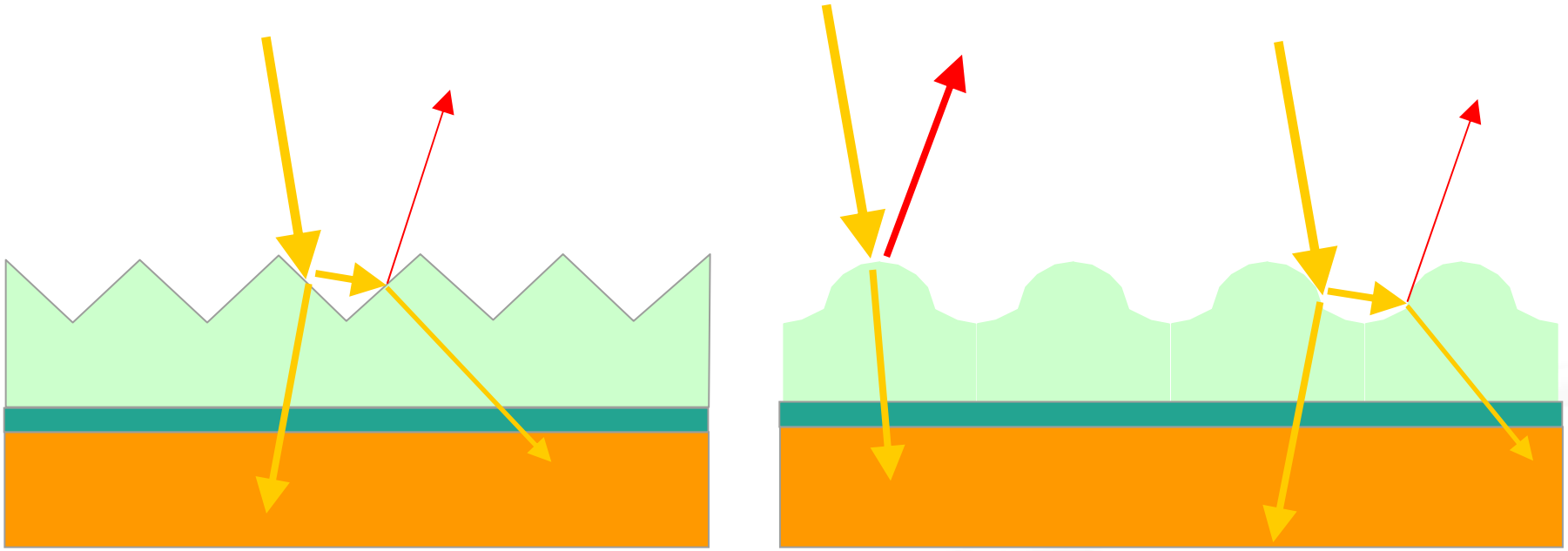
How does it look like?

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



Pictures by Michele Schiavoni & Patrick Gayout, SGR

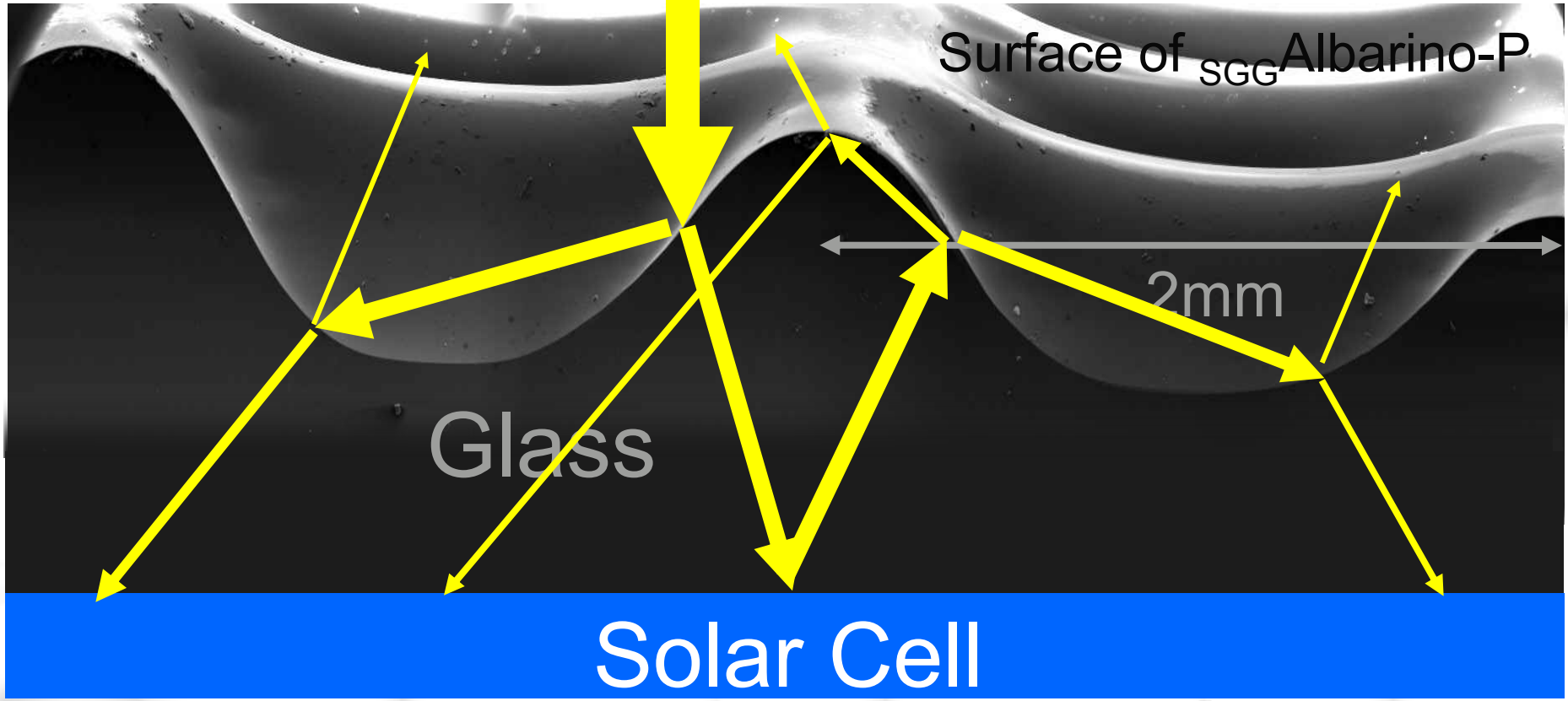
SGGAlbarino P: Principle @ small angles of incidence



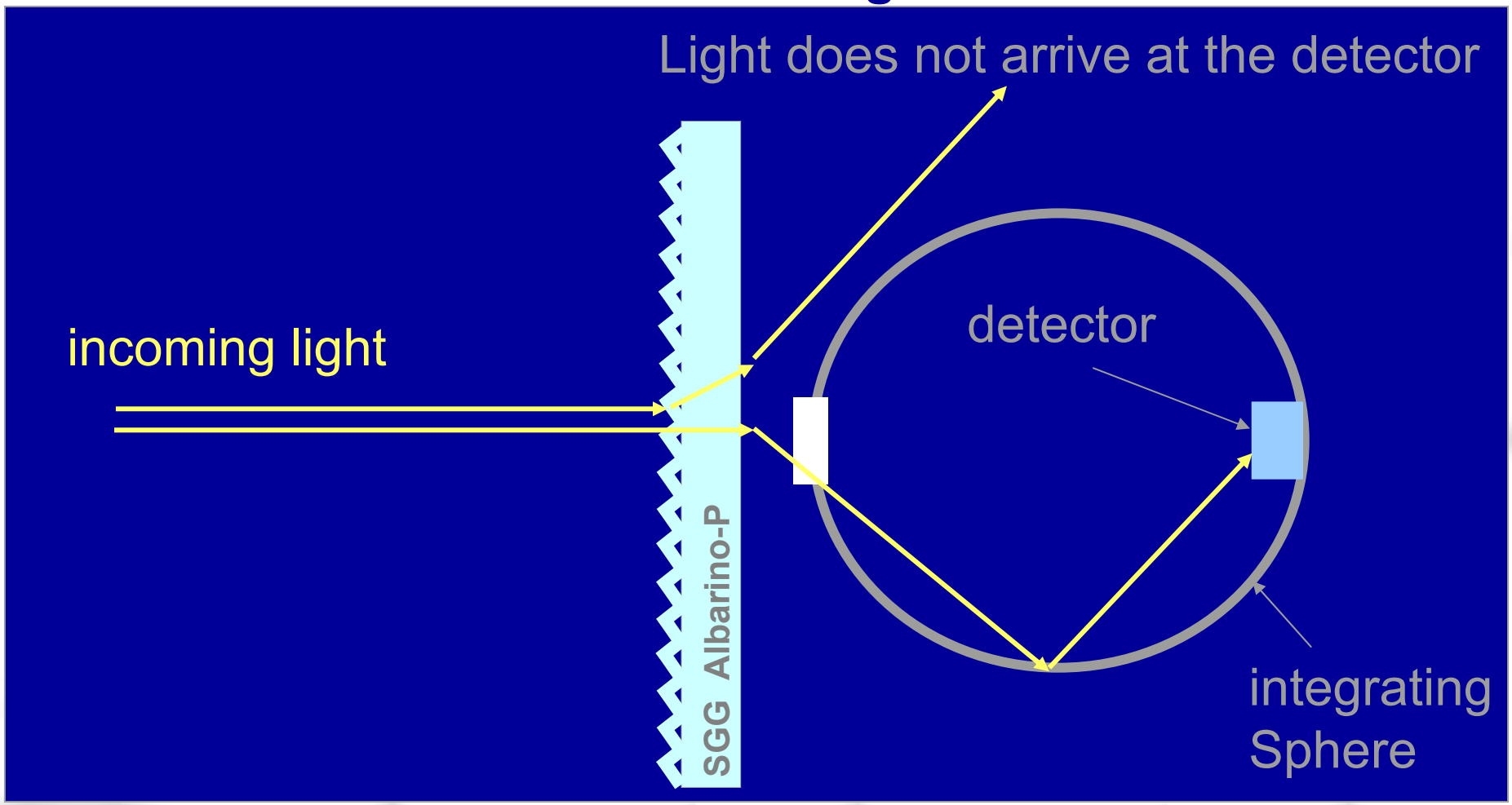
- Efficiency increase is due to light trapping (2 reflections too loose a light ray)
- In real Albarino P light trapping cannot take place for some positions on the glass cover

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)



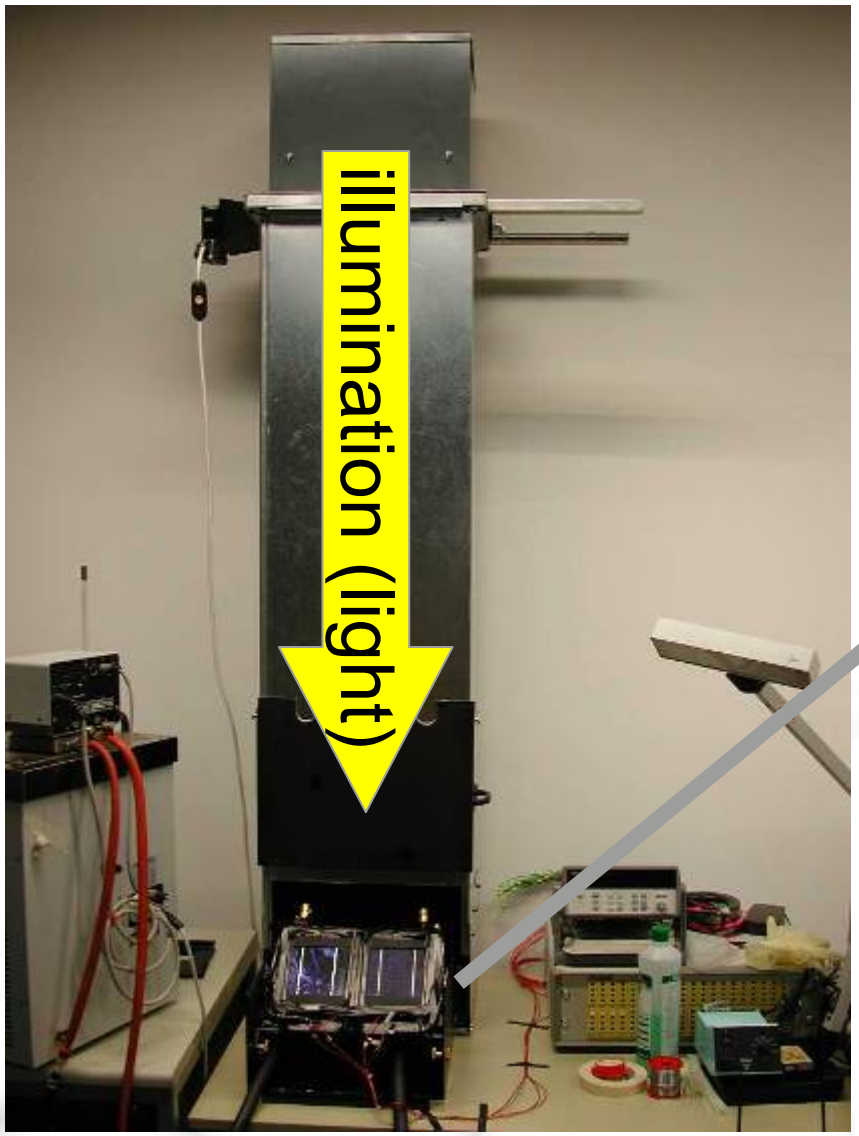
Problem to measure SGG Albarino-P or Albarino-G: method to measure the glass transmission fails with structured glass



current instead transmission

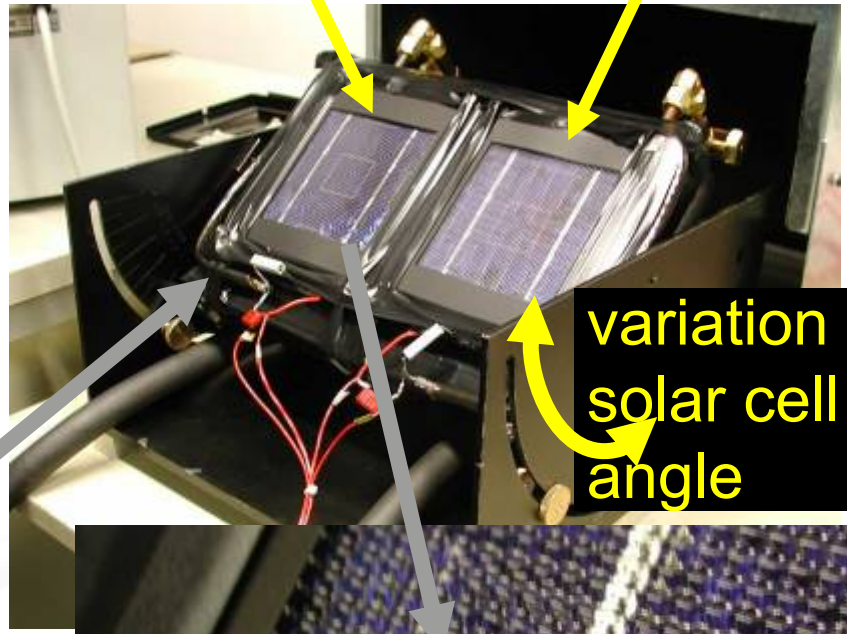
- making minimodules (e.g. 1 cell) to compare flat and structured glass
  - first measure cells to get correction factor
  - make 2 modules: one with flat, one with structured glass
  - measure directly neighboured or directly one after the other under solar flasher

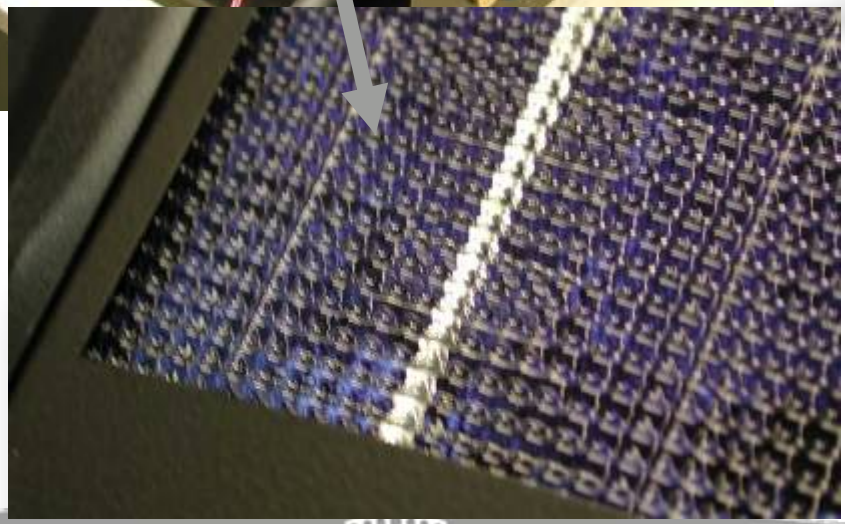
Measuring the Current increase



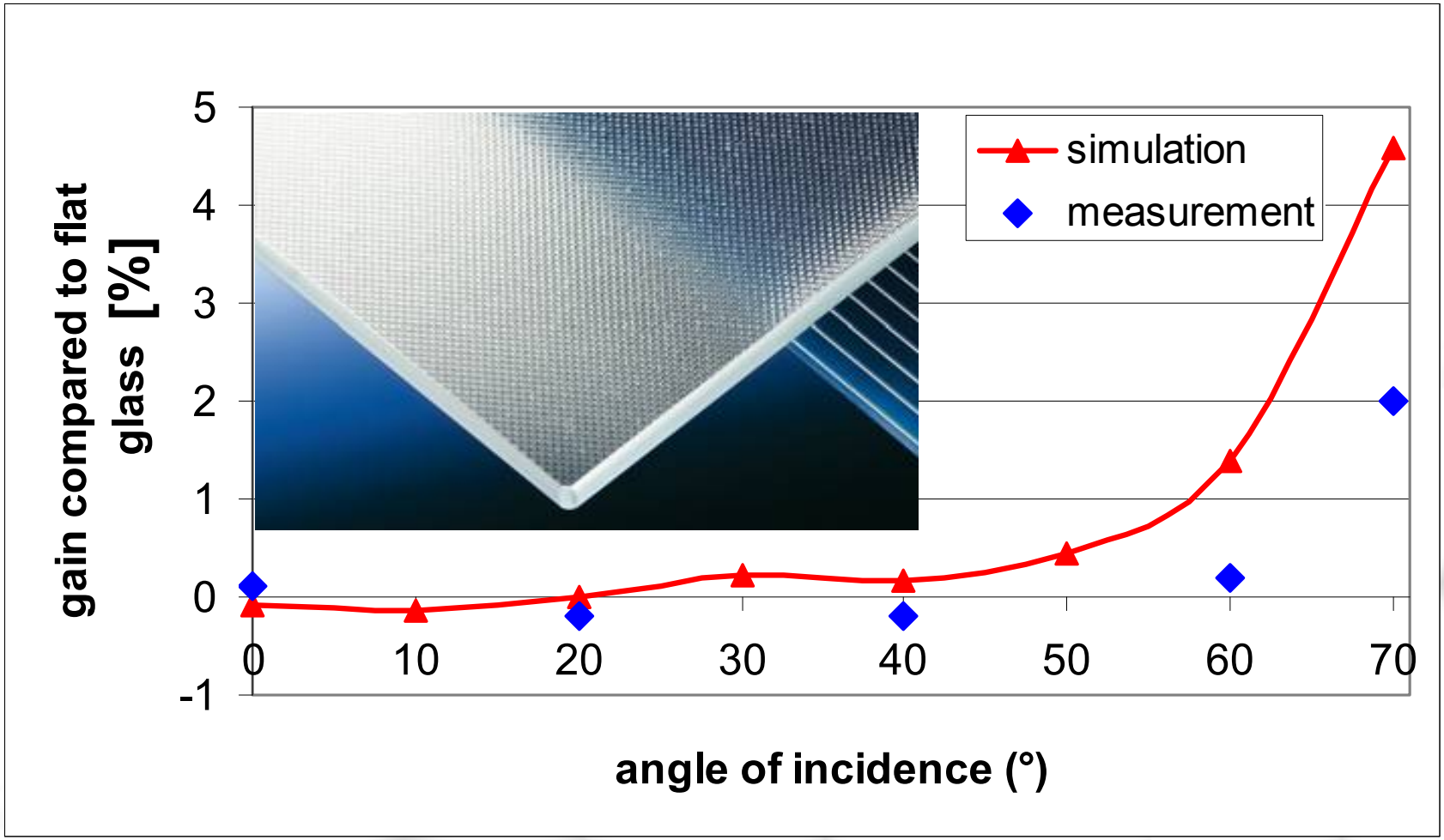
textured
x-white glass

non-textured
x-white glass





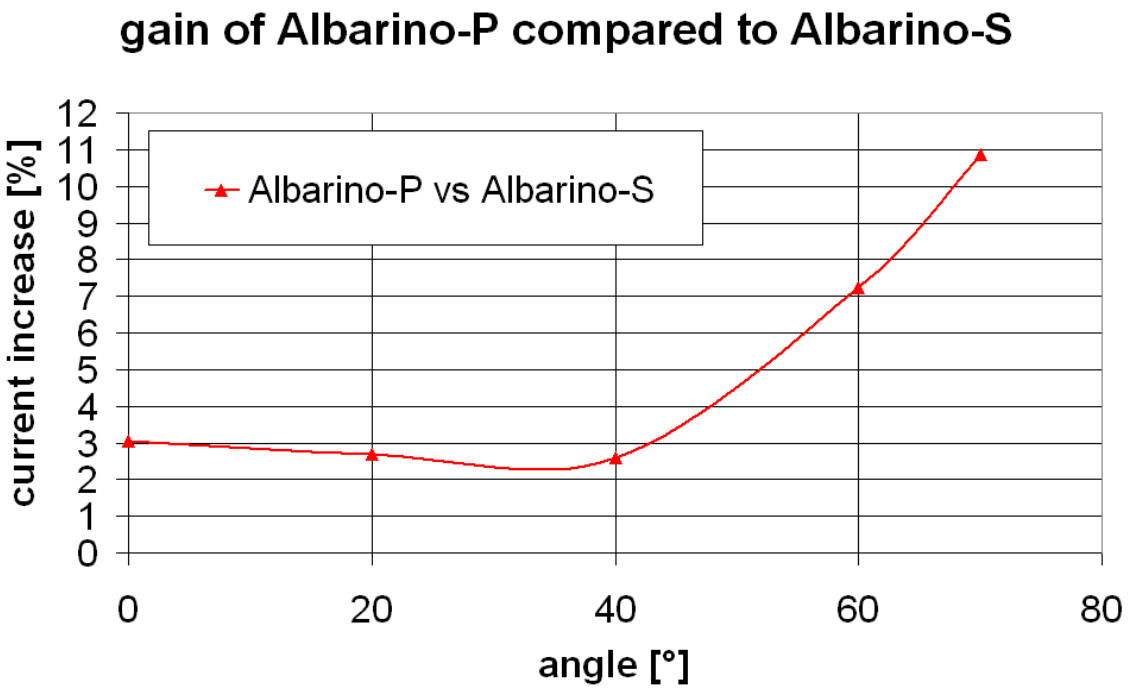
“normal” texture of patterned glass as face 1?



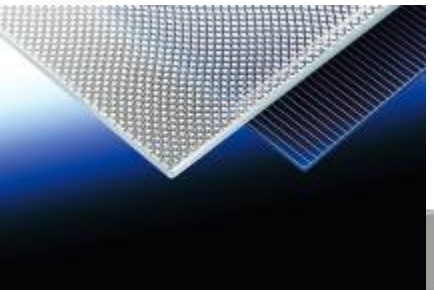
- advertised by some glass manufacturers
- sometimes believed by PV manufacturers!

Albarino´P (randomised pyramids)

- good efficiency enhancement



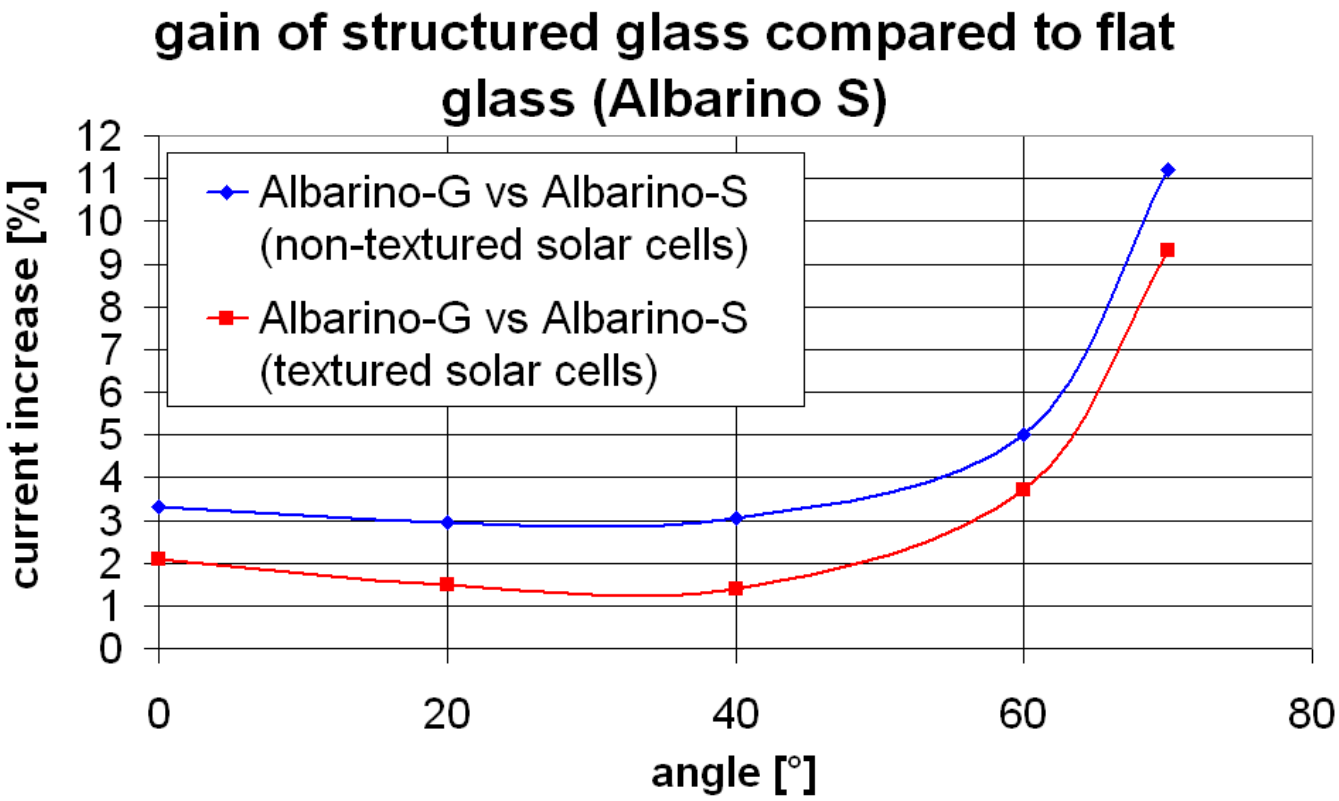
$$gain = [(I_{sc,\,textured} / I_{sc,\,ref}) - 1] x 100\%$$

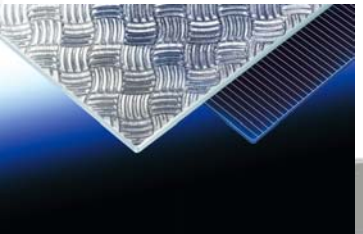


Albarino G (curved chess board)

- good efficiency enhancement measured in lab

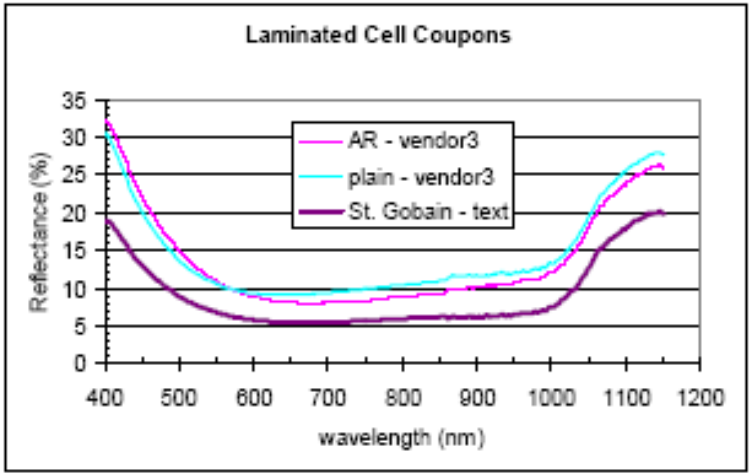
$$gain = [(I_{sc,\,textured} / I_{sc,\,ref}) - 1]100\%$$

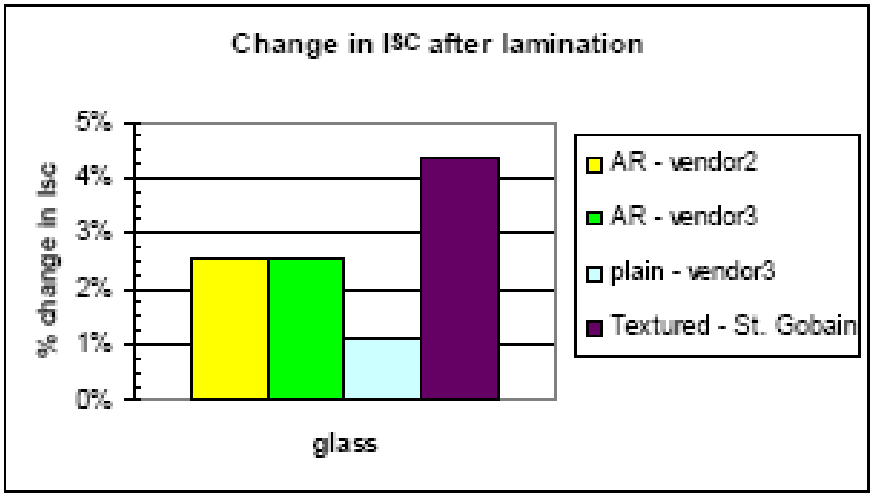




Albarino G

- results published at EUPVSEC 2007*





- outdoor tests at Sandia started (2008 January)

Glass	Isc (A)
AR – vendor2	8.06
plain – St Gobain	7.95
Textured – St Gobain	8.21
Gain: AR vs plain	1.4%
Gain: Textured vs plain	3.4%
Gain: Textured vs AR	**2.0%**

* A. M. Gabor et.al., TEXTURED GLASS AND ANTIREFLECTIVE-COATED GLASS FOR STRING RIBBON PV MODULES, 22nd EUPVSEC, 2007, p2728-273(

Testing outdoors of solar test modules

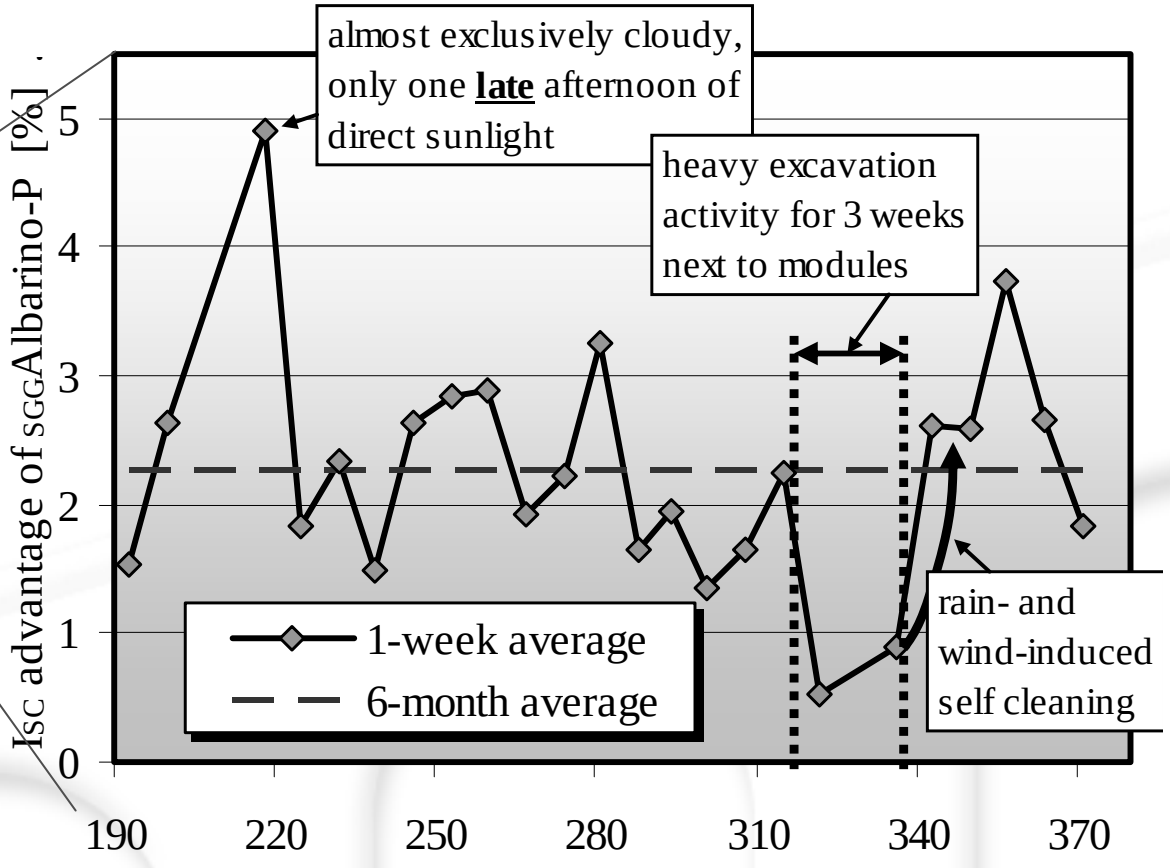
- oriented strictly to the south
- angles of incidence
  - Germany: 10°, 30°, 45°, 60°, 90°
  - Spain: 30°
  - new test sites planned in Asia (Korea and China)
- Testing
  - PV module performance (measurement of short circuit current I_{sc} (no power tracking)
  - transmittance of glasses
  - dust accumulation (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



self-cleaning → only short-time dust accumulation

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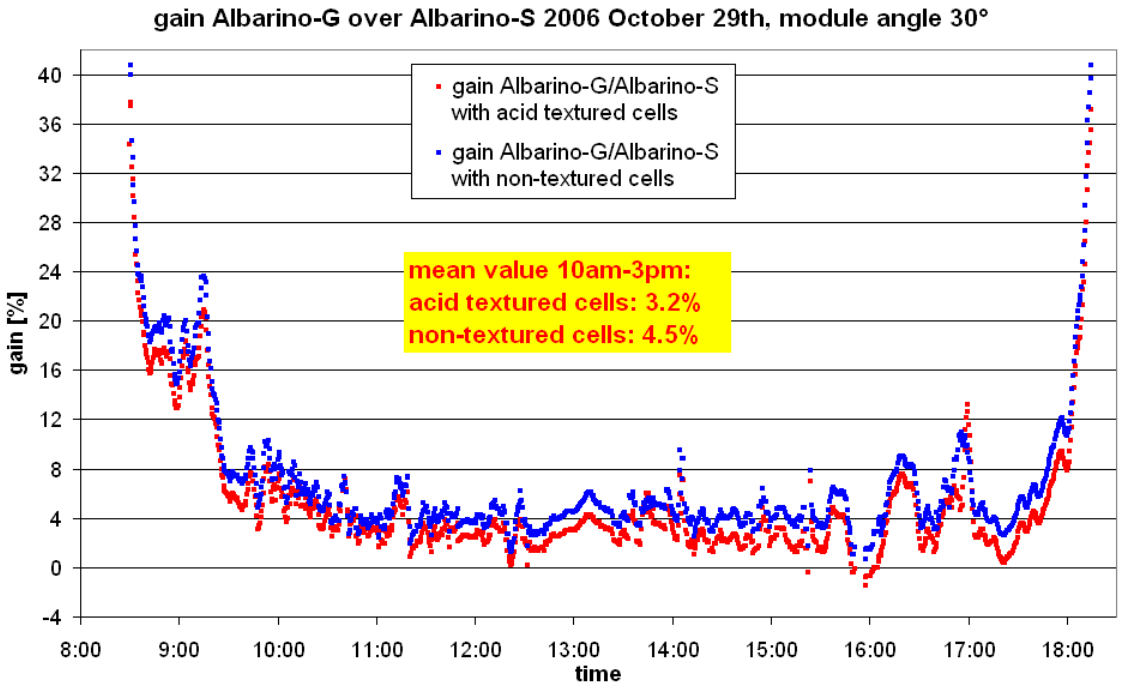
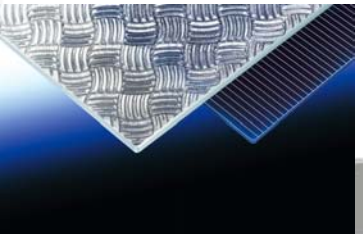
results outdoor test façade Germany

- 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



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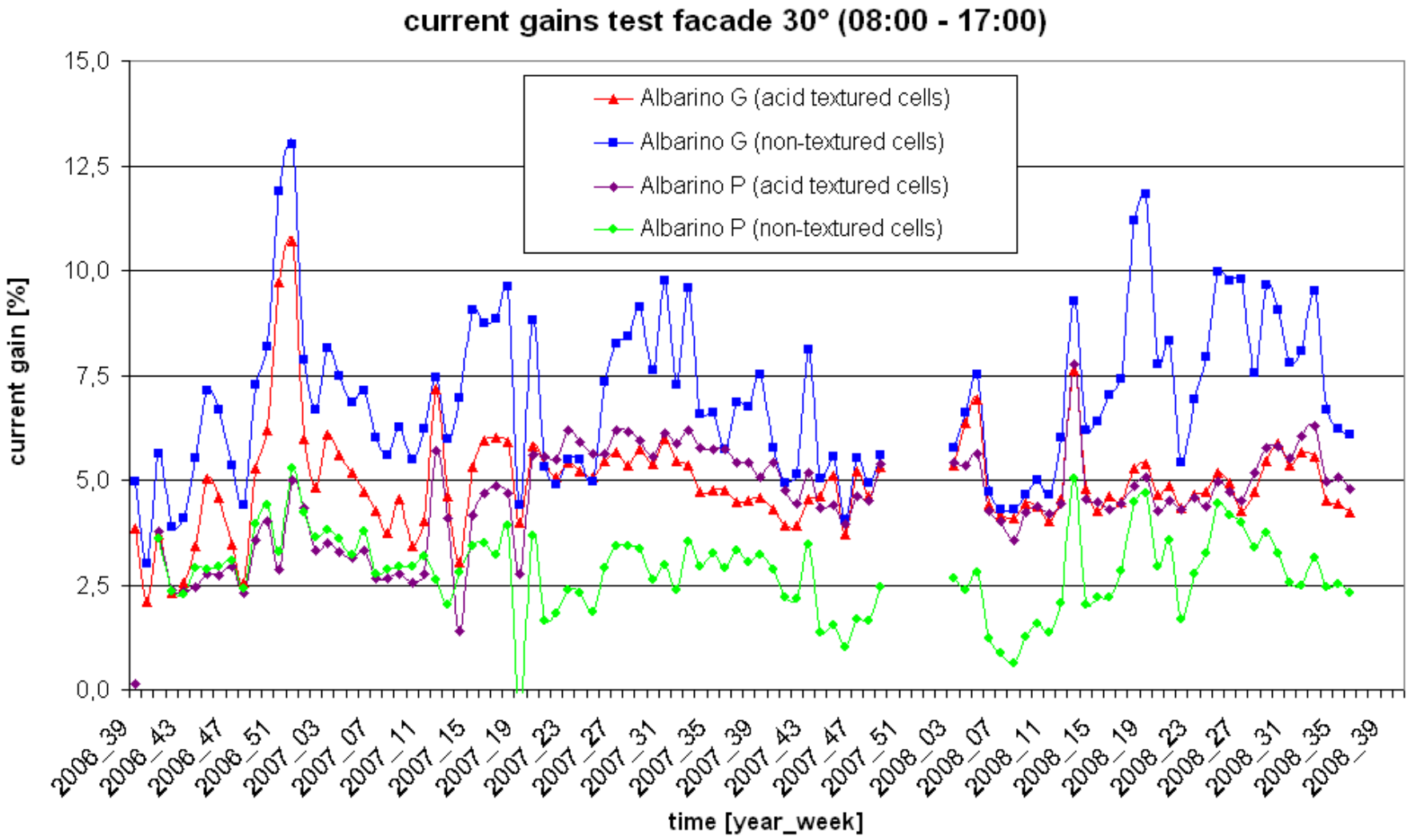
results outdoor test facade Herzogenrath



- annual yield ~ 5%

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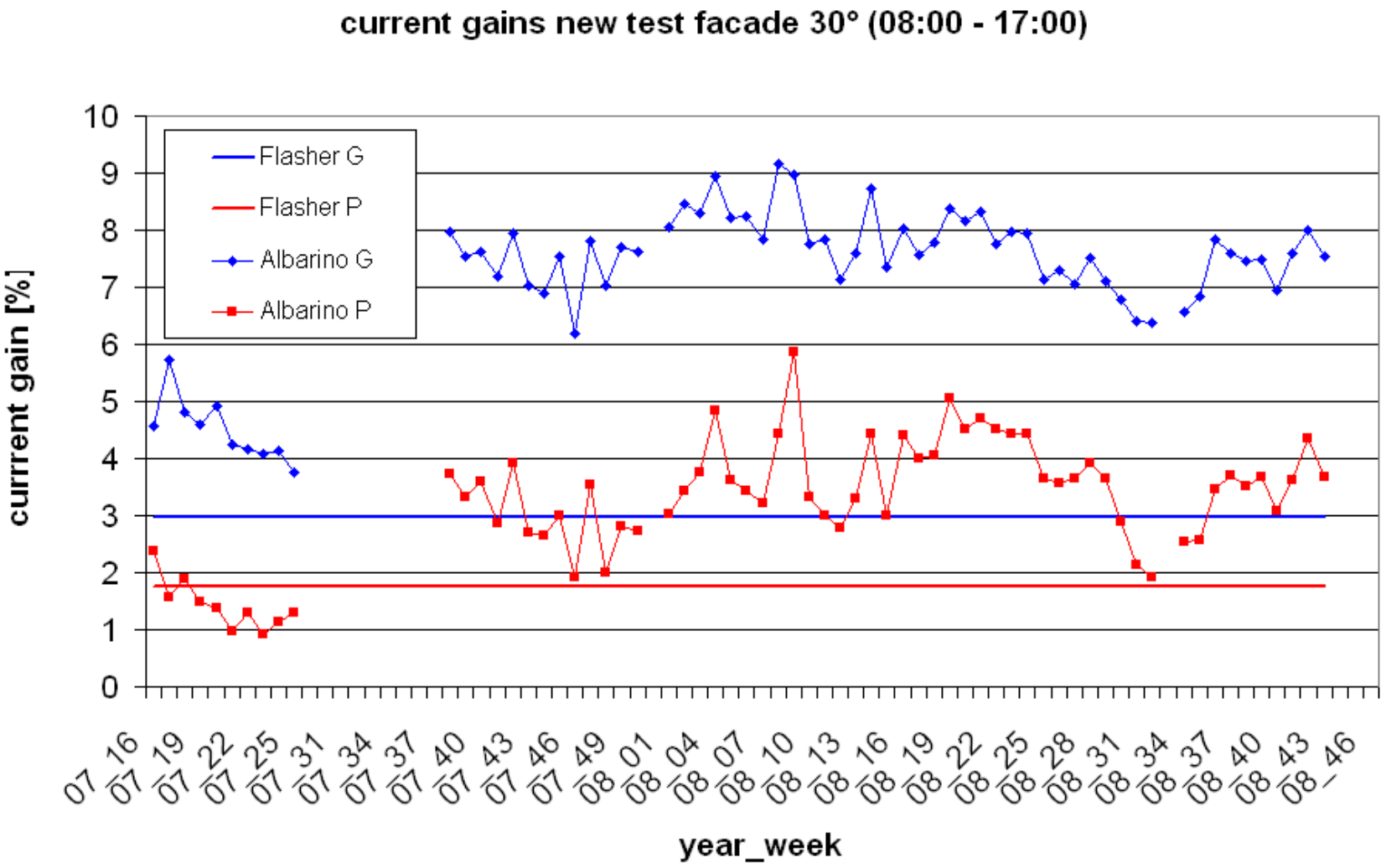
outdoor testing in Almunia Spain

- climate: sub-tropical, continental, dry summer

results outdoor test façade in Spain

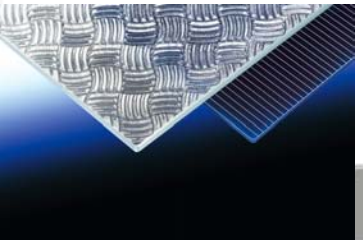


results outdoor test façade in Spain

- 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 feed-back 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 feed-back from customers in terms of soiling and kWh/kWp

Thank you very much for your attention!

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