BiFaTest: Characterization of bifacial solar cells and modules

Characterization of bifacial mini-modules

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- Summary

Anhalt University of Applied Sciences

- largest university of applied sciences in Saxony-Anhalt
- ~8,000 students (over 2,600 international students)
- bachelor´s- and master´s degrees, full time and distance learning programs

Research:

- BMBF funding „Inovative Hochschule“ www.forza-anhalt.de
- Pratner of TruePower^{TM} Alliance of SERIS
- BMBF funding „Wüstenmodule“ (challenges of desert module applications)

Test facility at HSA
PV Module and System monitoring

- Flexible **mounting structures** for different applications of bifacial modules
- **PV module monitoring** to measure maximum power output in real operating condition
- **30 kWp grid-connected PV system*** consist of mono-, polycrystalline and thin-film technologies
- **High-precision** meteorological equipment for on-site measurement of environmental parameters
- **Indoor test facility** to characterize PV modules (mono-/bifacial) acc. to IEC standards
    - currently under construction/investigation

*Joint R&D project with SERIS (www. truepoweralliance.com)

Façade

Open-rack

Meteostation

Motivation

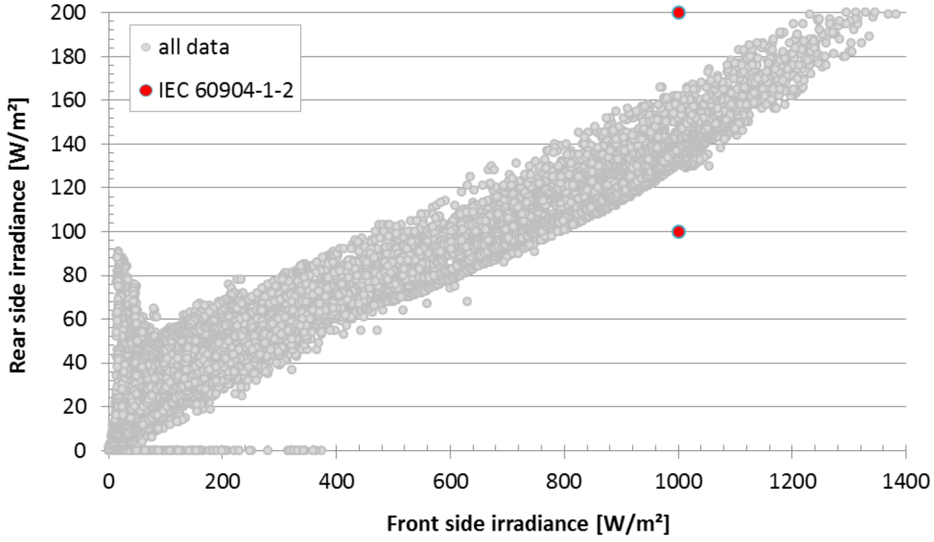
BiFaTest: Characterization of bifacial solar cells and modules

- **Energy yield measurements**
  - short-term and long-term performance of bifacial modules in specific applications (e.g. façades)
  - Deverlopment of irradiance measurement methords for bifacial (e.g. Bifacial reference cells or mini modules) → Mini module charachterisation
- Development of a **LED-cell and module tester** with front and rear side illumination
  - Requirements on rear side illumination (intensity, spectrum)
  - Definition of measurement protocols for energy rating (e.g. IEC61853 part1 and 2)
  - Sufficient characterization method for laboratory and industry use
- Sufficient **Energy yield prediction model** based on indoor characterization methods
  - Including PV cell and module properties

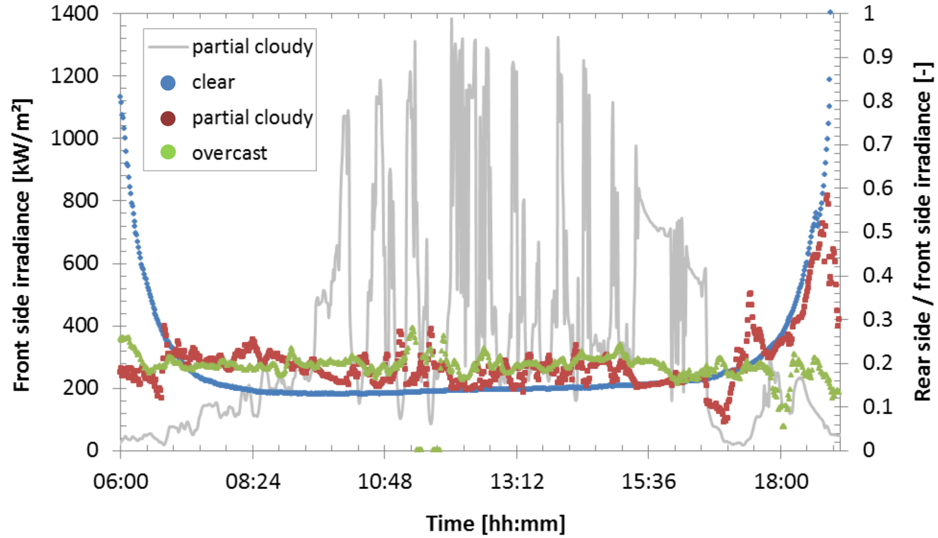
Definition measurement protocol

Front and rear side irradiance

- Location:
  - Bernburg (Germany; 51°N, 11°E)
  - South orientated open-rack with 35° inclination, subsurface: grass
  - Pyranometer (POA and albedo)
  - typical days in June/July ’18 - clear, partial cloudy and overcast



- Ratio of rear/front side irradiance:
  - Clear day: 0.14
  - Partial cloudy: 0.15 - 0.25
  - Overcast: ~0.2



- Rear side irradiance with grass as subsurface at 1000W/m²:
  - $G_{rear,max}$ = 160 W/m²
  - $G_{rear,avg}$ = 145 W/m²
  - $G_{rear,min}$ = 130 W/m²

[1] IEC 60904-1-2 Draft V. Fakhfouri et al., 3rd bifi PV workshop 2016, Miyazaki, Japan

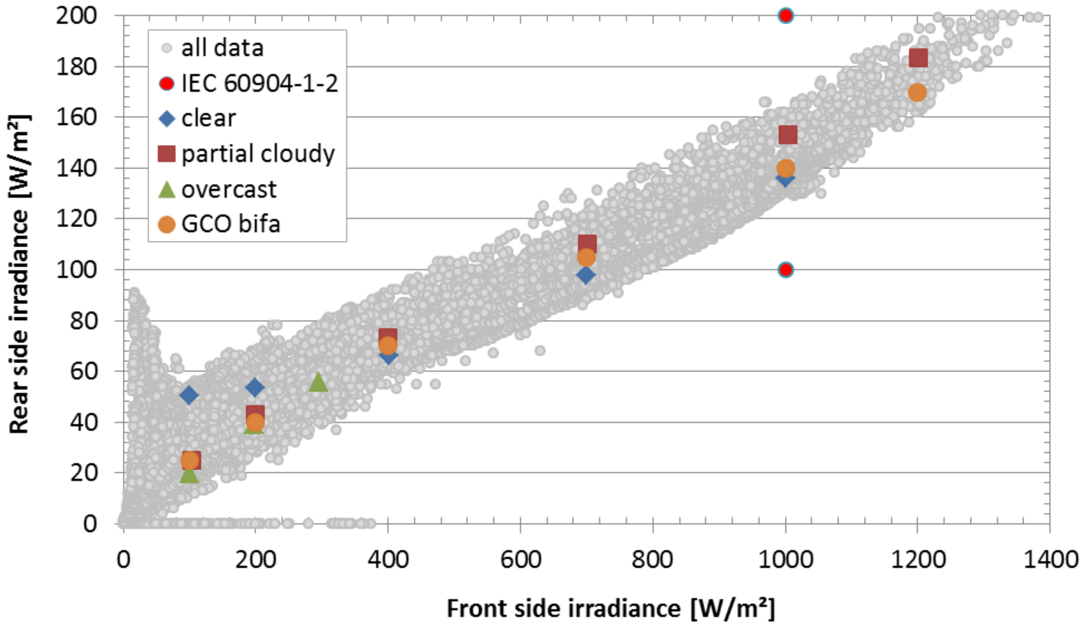
Definition measurement protocol
Front and rear side irradiance

- Definition of rear side irradiance for specific front side irradiance
- selected from clear, partial cloudy and overcast days
- open-rack conditions with grass subsurface
- Pyranometer 1.4m above ground

Selected iradiance range:

Gf [W/m²]	Gr [W/m²]
1200	170
1000	200
1000	140
1000	100
700	100
400	70
200	40
100	25

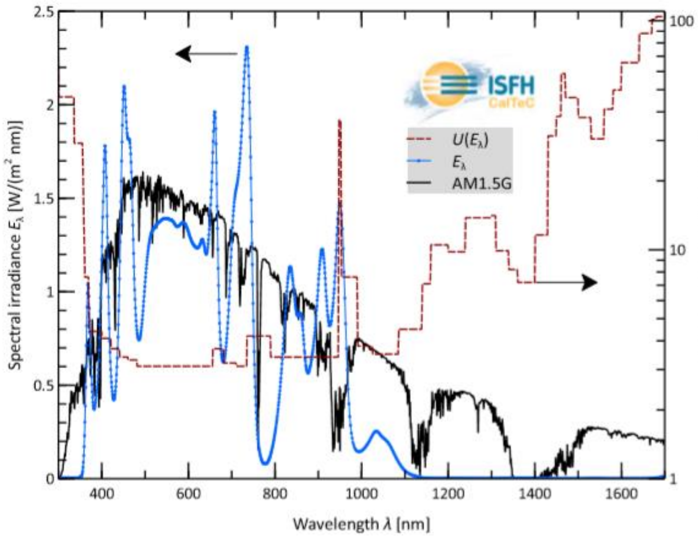
For this study Gr set to 100W/m²



Indoor test set-up
Single and double side illumination

- WAVELABS SINUS-220 LED solar simulator as front side light source
- WAVELABS LED rear side light engine as rear side light illumination (prototype)
- Spectrum: class A++ (±5%) for both light sources*
- Full spectrum flexibility unlike AM1.5g or even single wavelengths ranges
- Step less irradiance range for both light sources:
  - Front: 100 to 1200 W/m²
  - Rear: 100 to 1000 W/m²

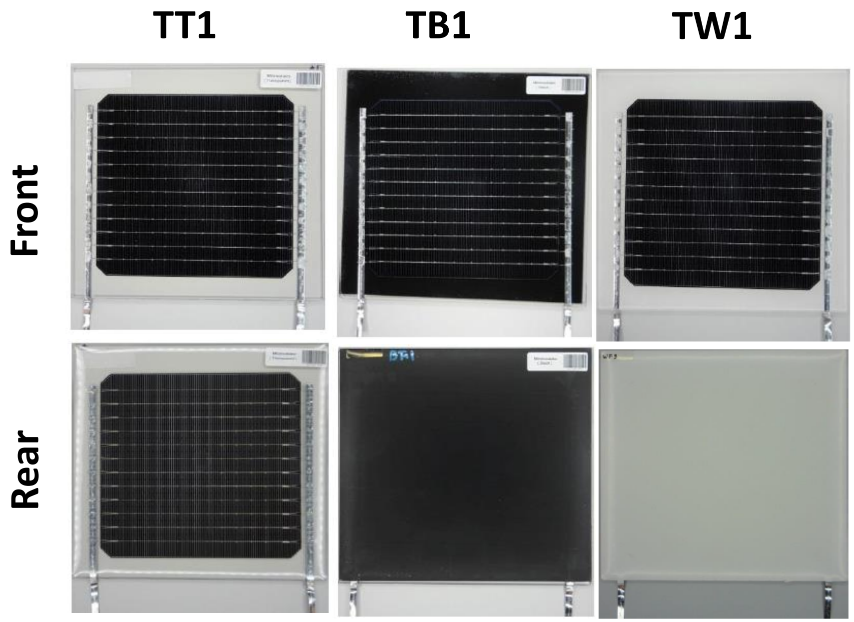
2nd light source as rear side illumination



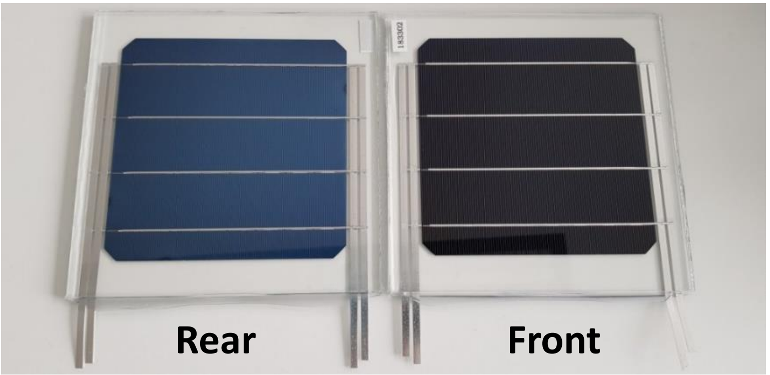
*certified by Fraunhofer CSP (SINUS-220) and ISFH CalTeC (rear side illumination)

Samples
Bifacial mini-module

- Group I:
  - Glass/ transparent backsheet (BS)
  - Multi wire
  - Sample with TT1
- Group II:
  - Glass/glass
  - Different numbers of busbars
  - Sample marked with GG
- Group III:
  - Glass/black and white backsheet
  - Multi wire
  - Samples with TB or TW



Sample with transparent and colored BS

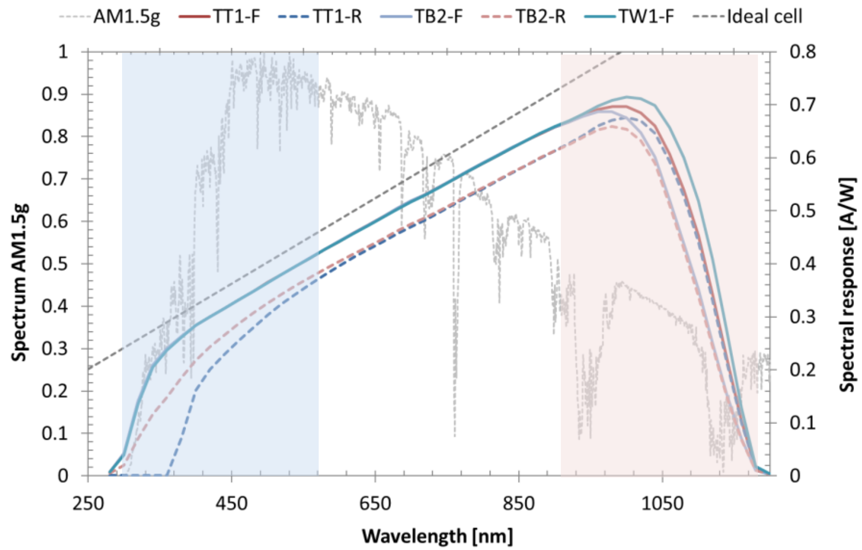


Sample with four busbars (GG02)

Results
Spectral response and low light behavior

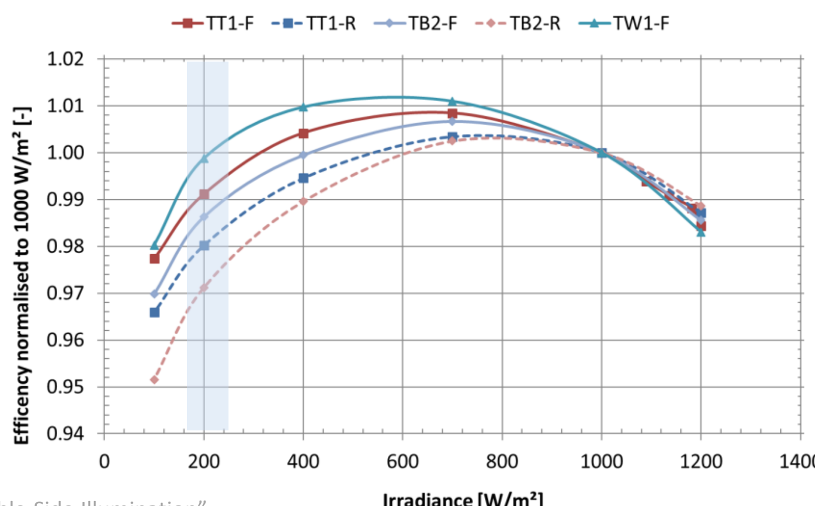
SR data:

- white BS shows highest response
- SR of the rear-side over the full wavelengths range is reduced
- optical losses of rear-side due to transparent BS properties (<650nm)
- higher losses for TB2-R (glass/EVA) (>950nm)



Low light behavior at 200W/m²:

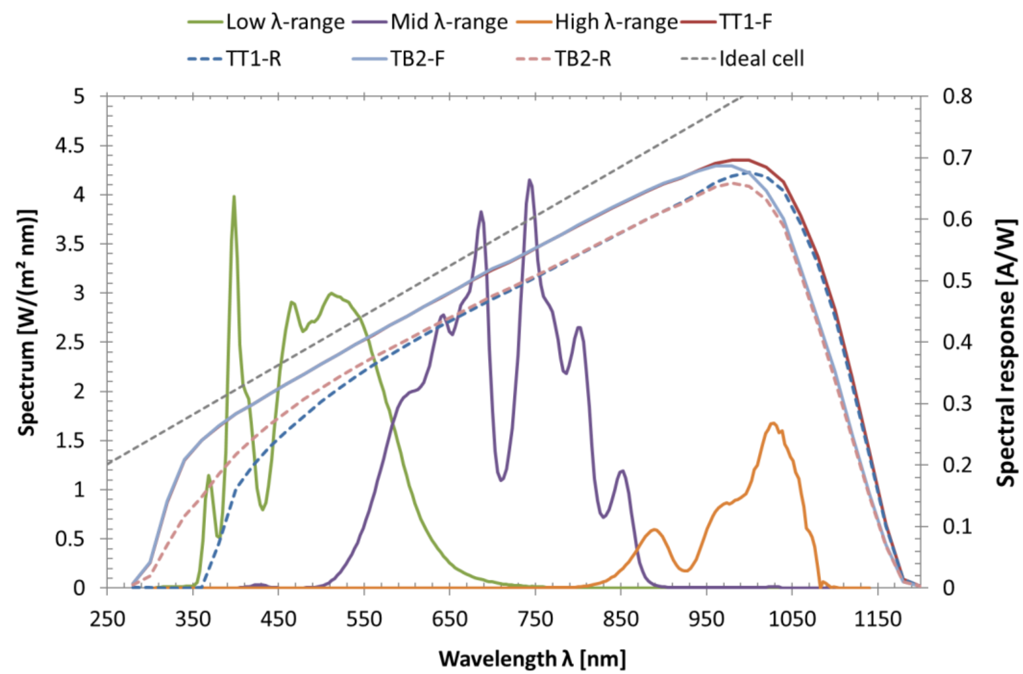
- TT1-F/TT1-R: -10%
- TT1-R/TB2-R: -2.7%



[1] S. Dittmann, PVSEC 2018 "Characterization of Bifacial PV Mini-Modules Using Front- and Double-Side Illumination"

Results
Spectra Unlike AM1.5g

- Isc measurement at spectra unlike AM1.5g
  - Low λ-range 350-650nm
  - Mid λ-range 550-850nm
  - High λ-range 850-1000nm
- Losses in current generation in comparison to TT1-F
- Highest losses with transparent BS in low λ-range but lowest in the high λ-range (TT1-R)



Spectrum	TT1-F	TT1-R	TB2-F	TB2-R
Low λ-range	0.00%	-19.84%	-0.16%	-14.04%
Mid λ-range	0.00%	-7.69%	-1.10%	-8.79%
High λ-range	0.00%	-3.92%	-10.25%	-12.53%

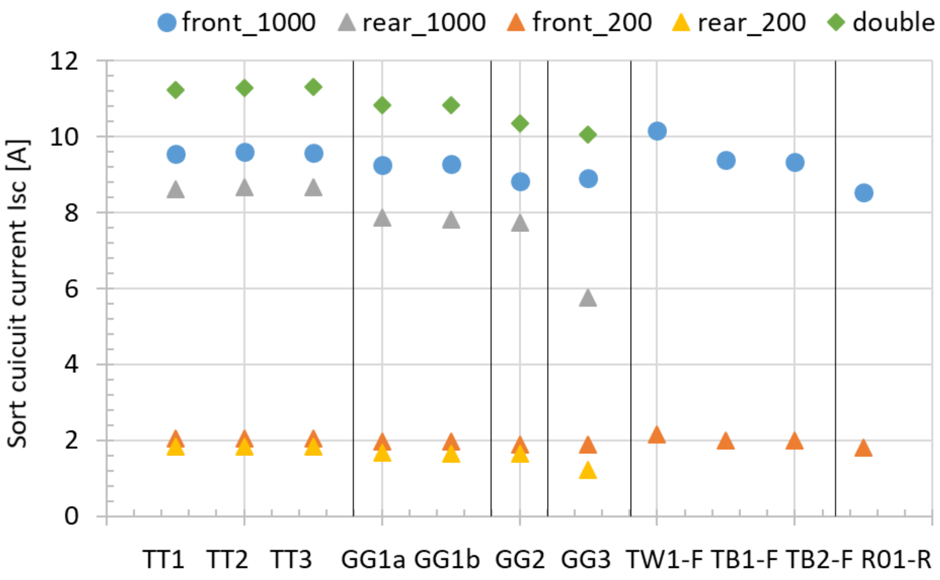
[1] S. Dittmann, PVSEC 2018 "Characterization of Bifacial PV Mini-Modules Using Front- and Double-Side Illumination"

Results

Single side and double side illumination

- Single side: Isc at STC and low irradiance*
- Double side: Isc at 1000 W/m² on front and 200 W/m² on rear side*

- Deviation between samples of same technology: ±0.2%
- Group I and II:
  - ~ 17% gain with double side illuminiation, GG3 13% gain
- Group III:
  - black BS -2.5% losses
  - write BS +6.5% gain
  - glass instead of transparent BS -1% losses

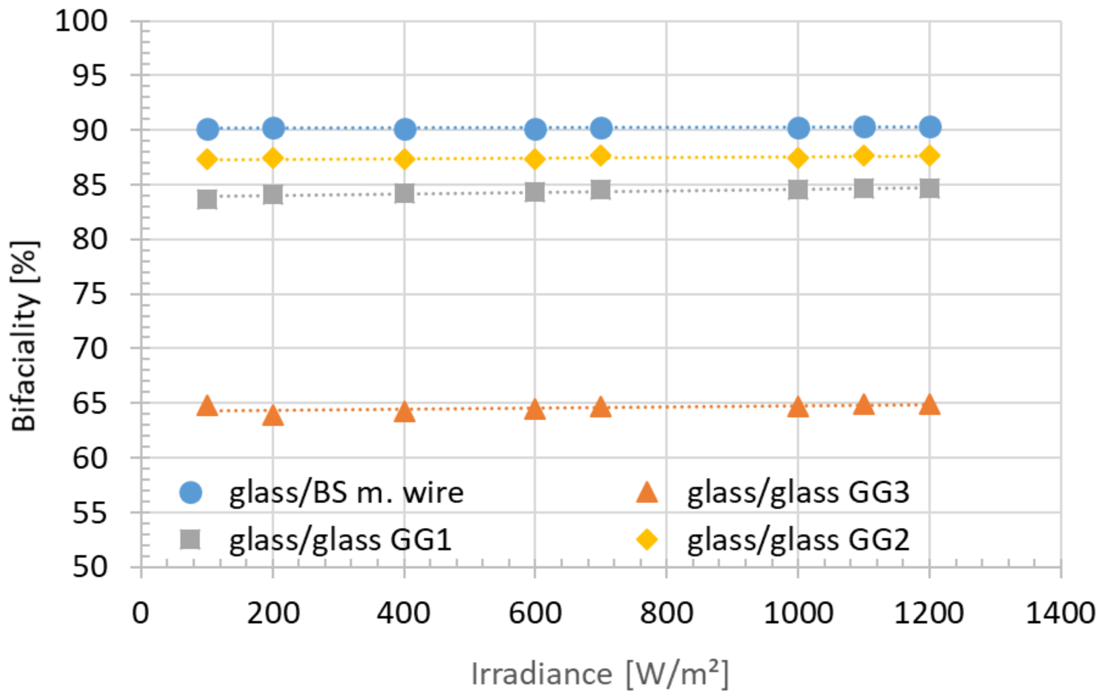


*Sample temperature: 25°C ±2°C, traceability: Fraunhofer ISE WPVS reference cell

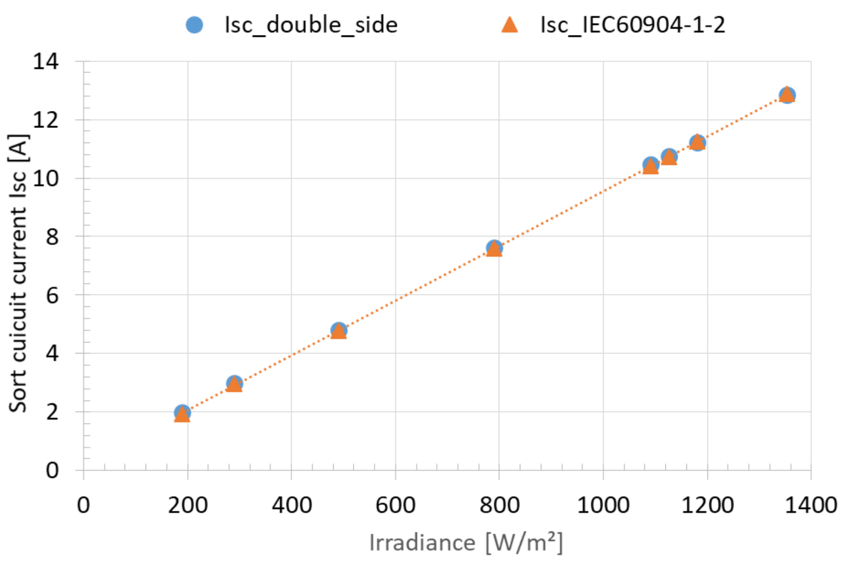
[1] Liu et al., Solar Energy Materials and Solar Cells, Volume 144, January 2016, Pages 523-531
[2] Koentopp et al., IEEE JOURNAL OF PHOTOVOLTAICS, VOL. 3, NO. 1, January 2013

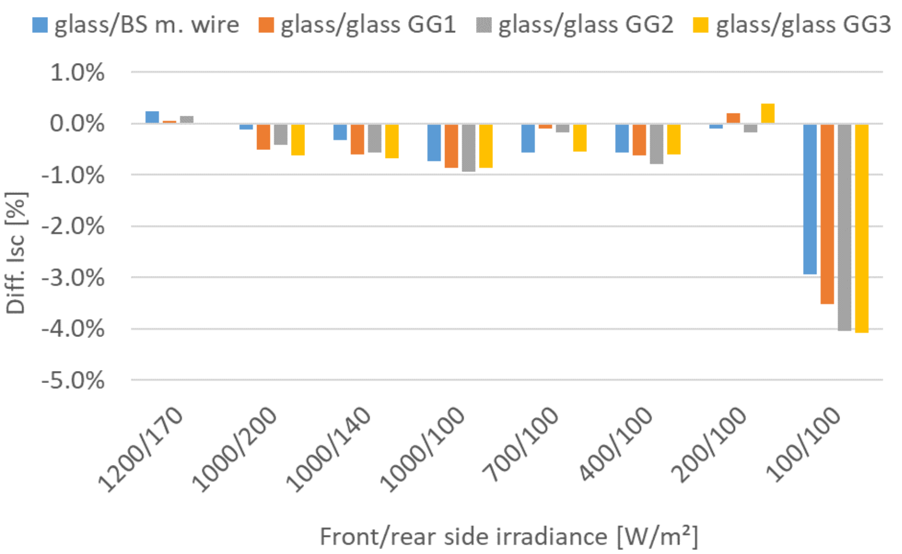
Results
Bifaciality at different irradiances

- Highest bifacility for glass/BS (TT) samples of about 90%, lowest for glass/glass GG3 with about 65%
- Bifacility is slightly lower for low irradiances (<1%)
- Deviation between samples of same technology ±0.5%



Results
Comparison of methods





- Comparison of IEC60904-1-2 (Ge - method) to double side illumination
- Differenz within ±1% at 1000 W/m² to 200 W/m²
- up to -4% difference for 100/100 W/m²

Summary

- Double side sun simulator based on LED with:
  - class A++ spectrum
  - flexible irradiance range of 100-1000W/m²
  - flexible spectra range
- Definition of measurement protocol for rear side irradiance at low irradiance as input for energy rating calculations such as IEC61853
- Transparent BS: losses of 20% in current generation for lower (<650nm) but lower losses for wavelengths >900nm in comparison to glass
- Bifacility is slightly lower for low irradiances (<1%)
- Double side measurement and IEC60904-1-2 draft approach show a good agreement, ±1% for irradiance >200W/m², up to ±4% at 100/100W/m²

Thank you for your attention

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