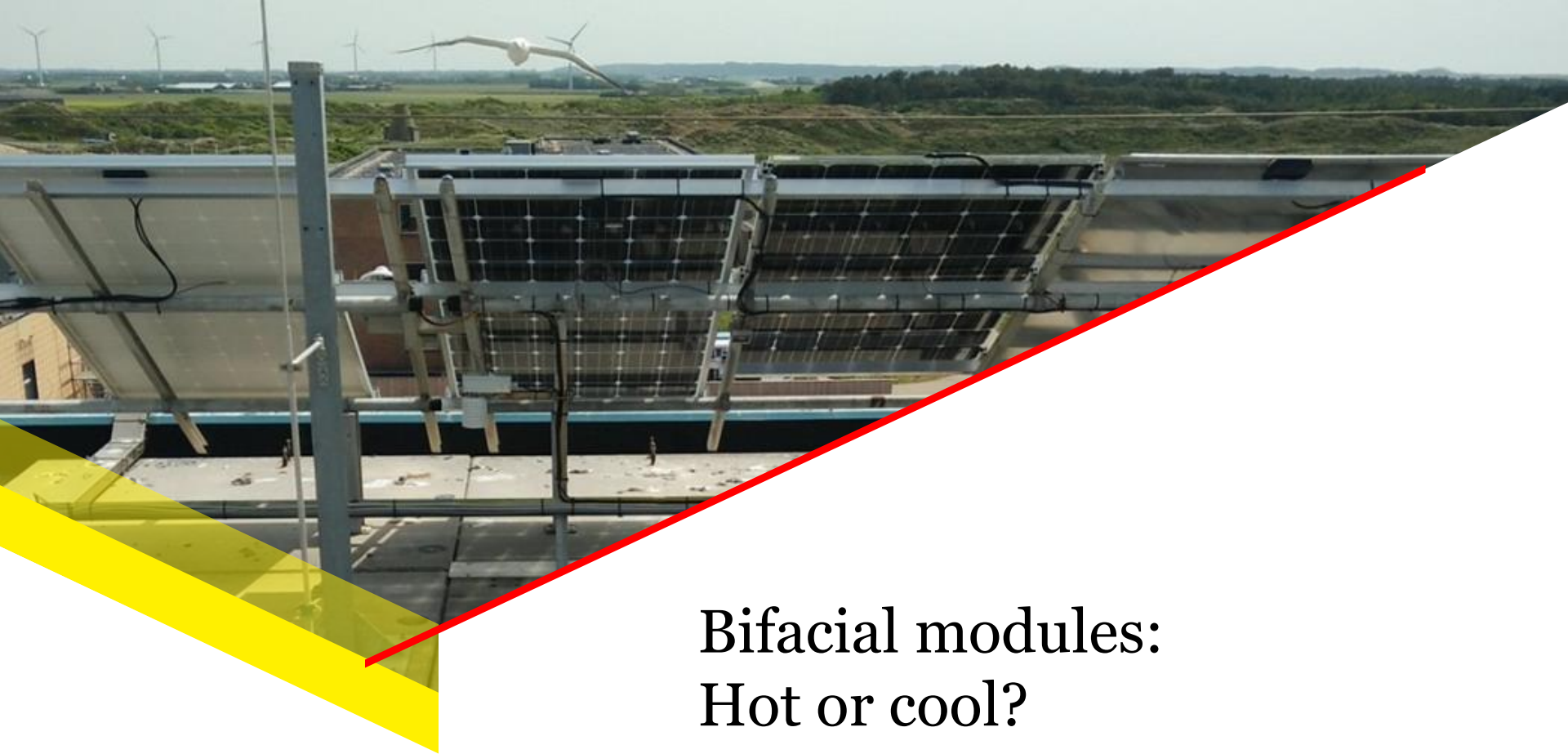


Bifacial modules: Hot or cool?

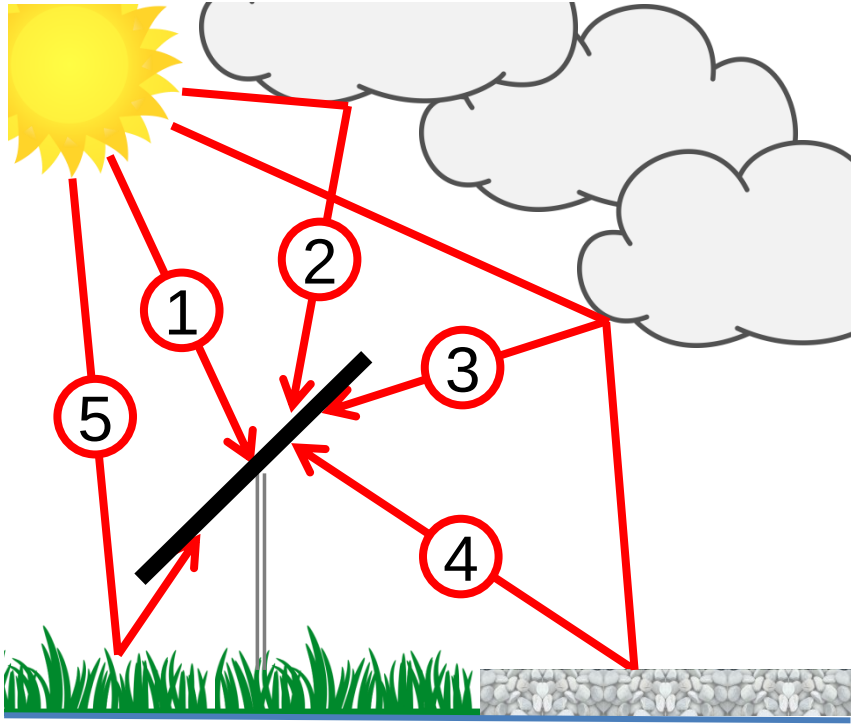
Bas Van Aken

ECN

Introduction

Motivation:

- Bifacial cells -> higher output
- Increased (parasitic) heating -> temperature up -> lower output



Acknowledge financial support from Dutch TKI-Urban Energy *Subsol* and TKI-toeslag *BING* projects
M.Sc. students Ebrar Özkalay and Sundeep Gali from Delft Univ. Tech.

Introduction

Motivation:

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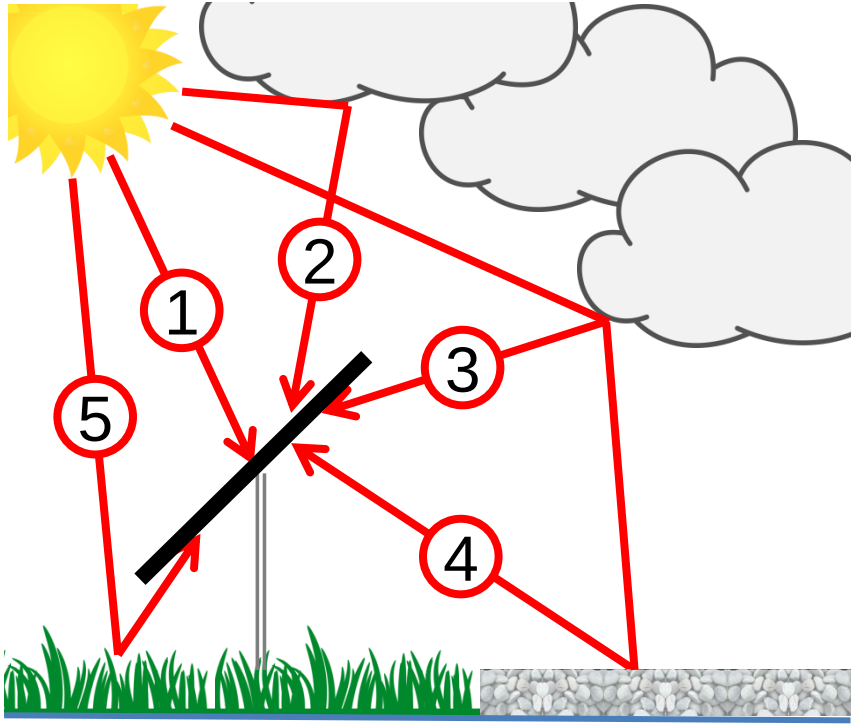
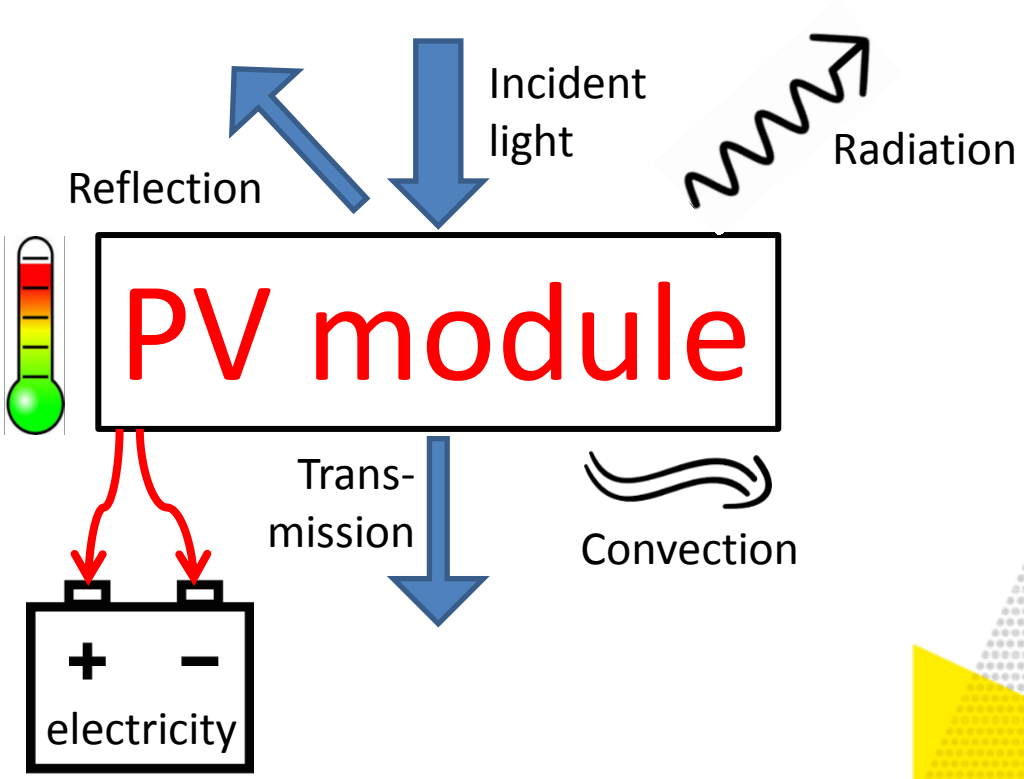
- Increased (parasitic) heating -> temperature up -> lower output



- Bifacial modules are hot:
  - Absorption? Higher current?
- Bifacial modules are cool:
  - Transmitted light? Better heat transfer?

Heat balance

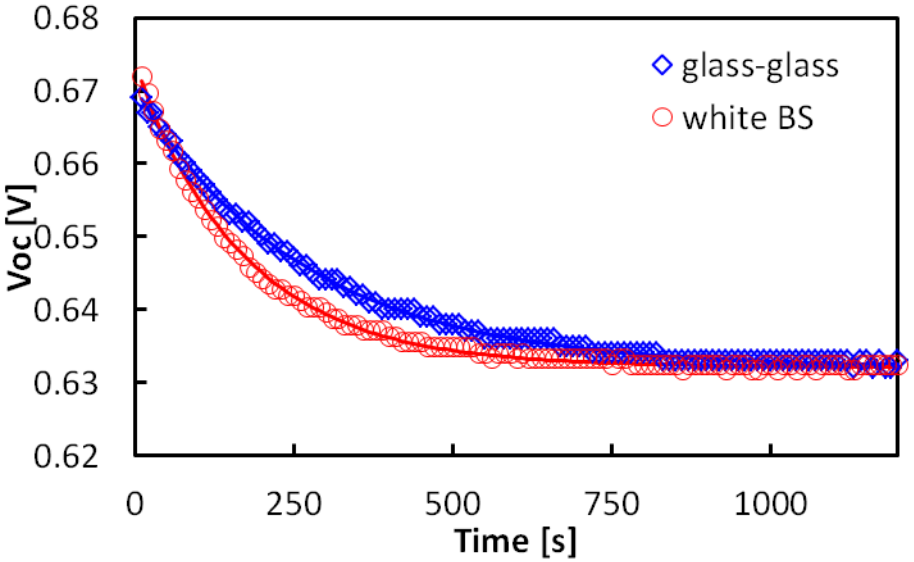
- Light
  - Reflected / transmitted
  - Absorbed
- Conversion
  - Electricity
  - Heat
- Heat loss
  - Radiation
  - Convection



Voc decreases with increasing cell temperature

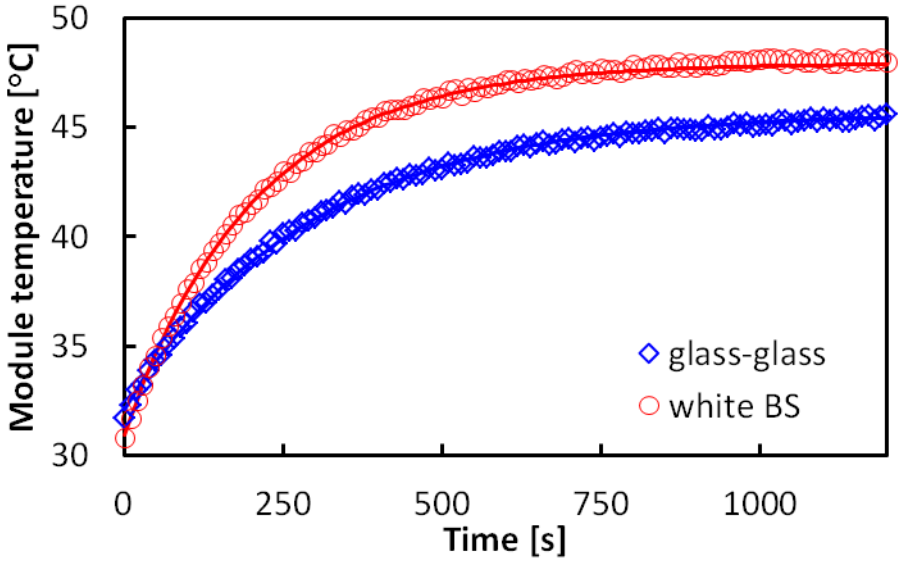
- Eternalsun steady state solar simulator
- 60-cell n-PERT modules
  IV-curves measured every 10 sec

- Voc decreases
  halftime = 180 s glass-glass
  halftime = 120 s white BS



Steady-state reached in a few minutes

- Tmodule increases
  halftime = 200 s glass-glass
  halftime = 140 s white BS
- The steady state temperature T_{eq} depends on effective heat input $G_{tot}(1-\eta)(1\text{-T-R})$
  and the effective heat loss coefficient h from radiation and convection



$$T_{eq} - T_{amb} = \frac{G_{tot}(1-\eta)(1-\mathrm{T}-\mathrm{R})}{h}$$

Effective heat input similar for laminates with bifacial cells; Al-BSF in g-g has higher heating

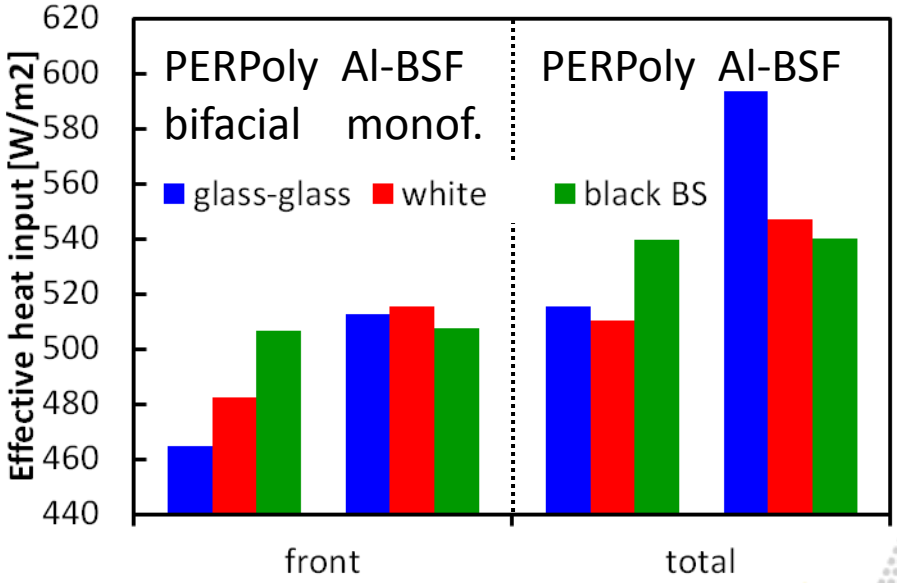
Measured in lab:

- on front and rear
- on active and non-active parts
- reflection/transmission
- IQE measurements

Calculate balance:

- thermalisation, free carrier absorption

note: black back sheet is black on cell side and white at rear side of panel



total area 1000 W/m²

front 1000 W/m²
rear 100 W/m²

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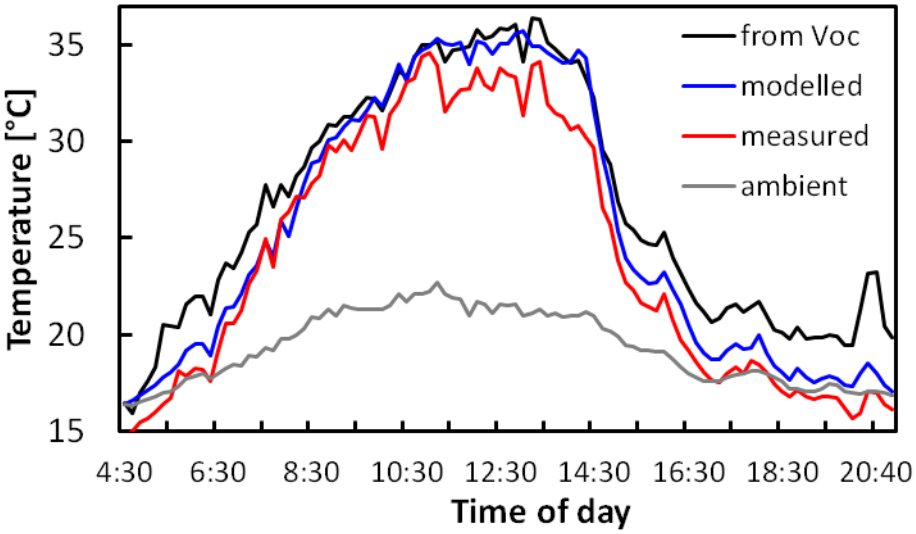
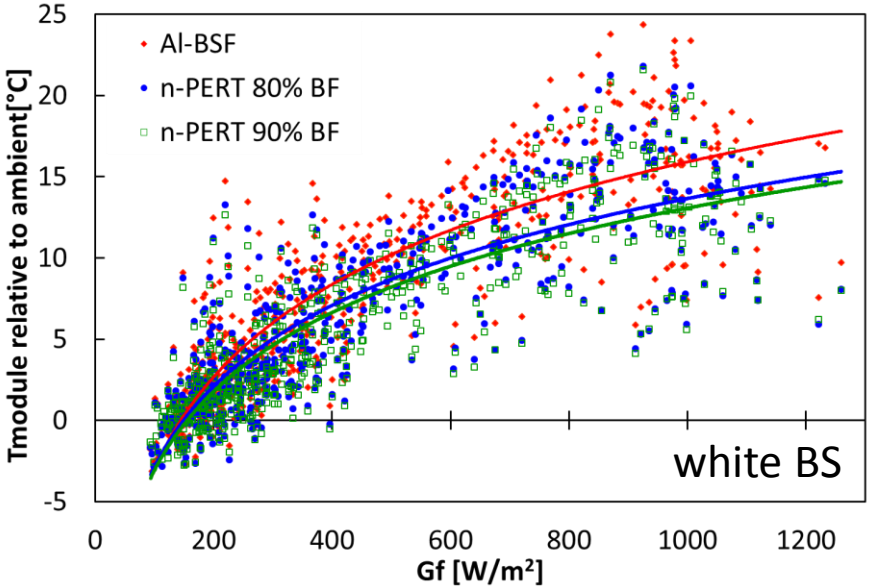
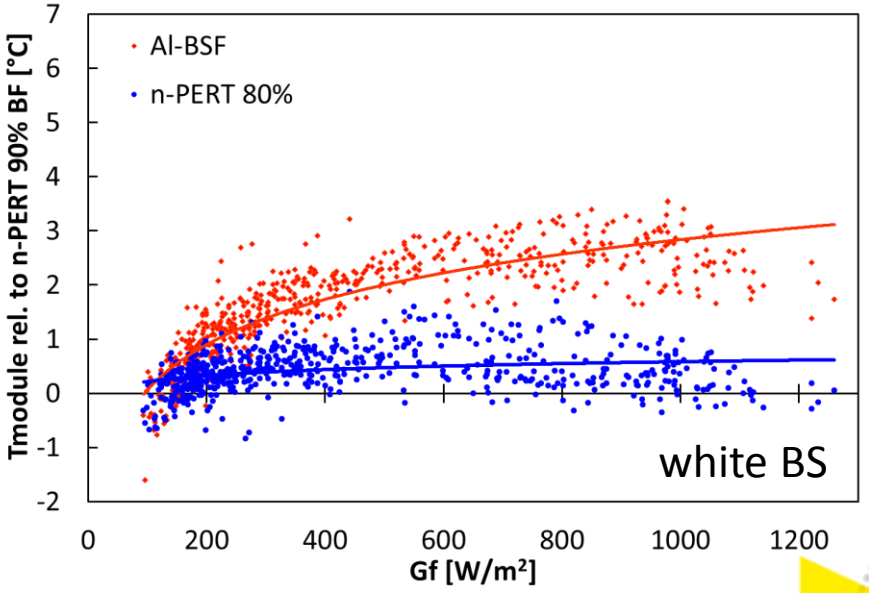
How to determine the module or cell temperature

- Measure voltage of thermocouple on rear of module
- Calculate cell temperature from STC Voc, measured irradiance and measured Voc
- Model temperature curve using irradiance and heat loss coefficient



Bifacial cells have lower temperature under outdoor conditions





- Increase in module temperature as function of front irradiance Gf
- At 1000 W/m² ΔT=13-16 K for single cell laminates

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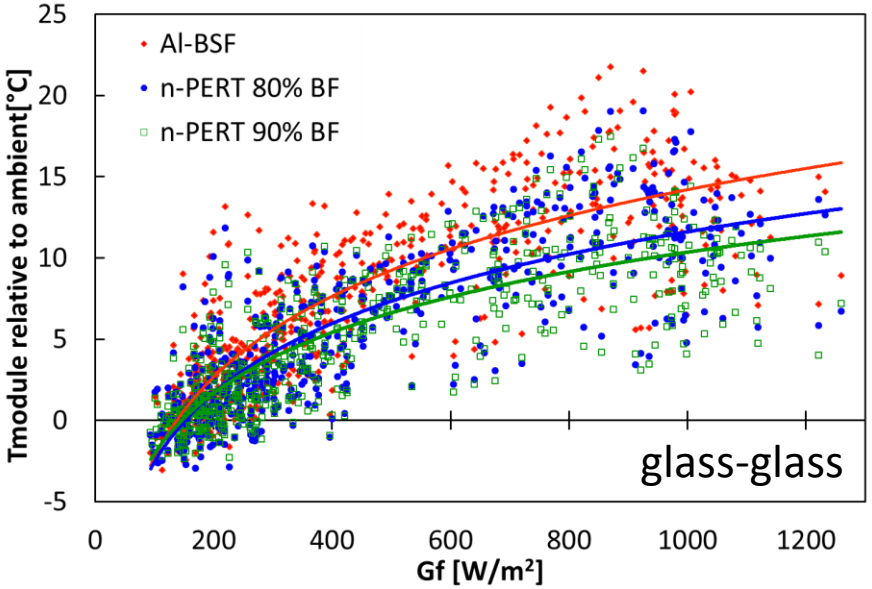
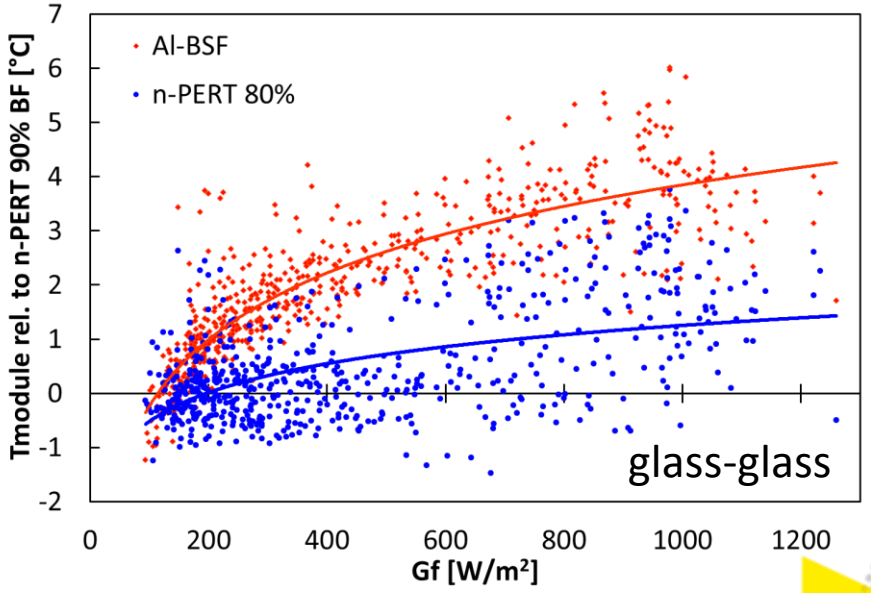
Lower ΔT for bifacial cells in bifacial laminates





- At 1000 W/m² ΔT=10-15 K

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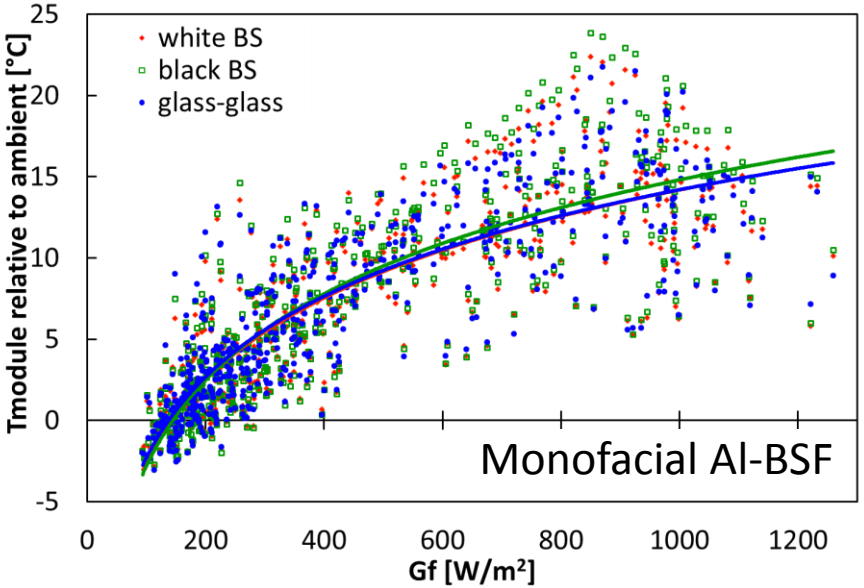
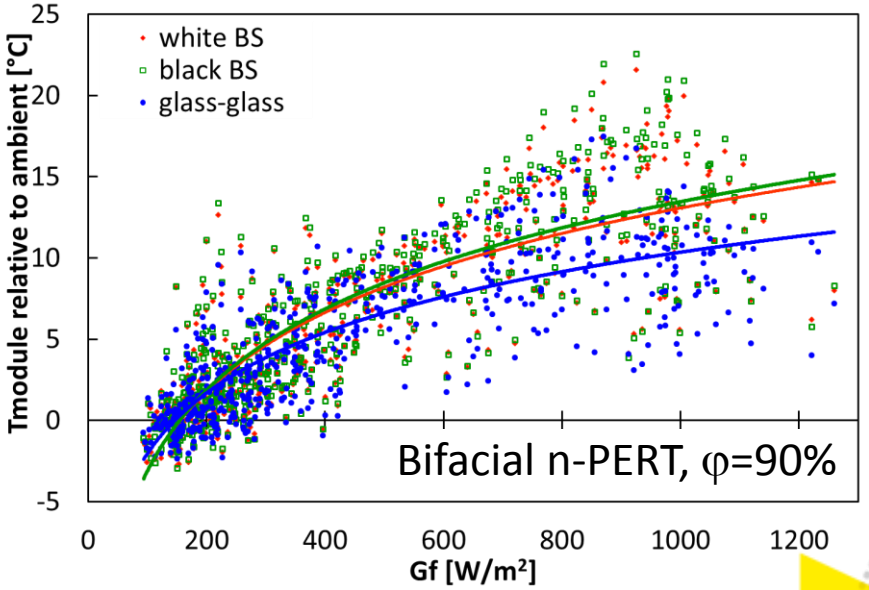
ΔT for glass-glass lower than expected from lab data, for both mono- and bifacial cells

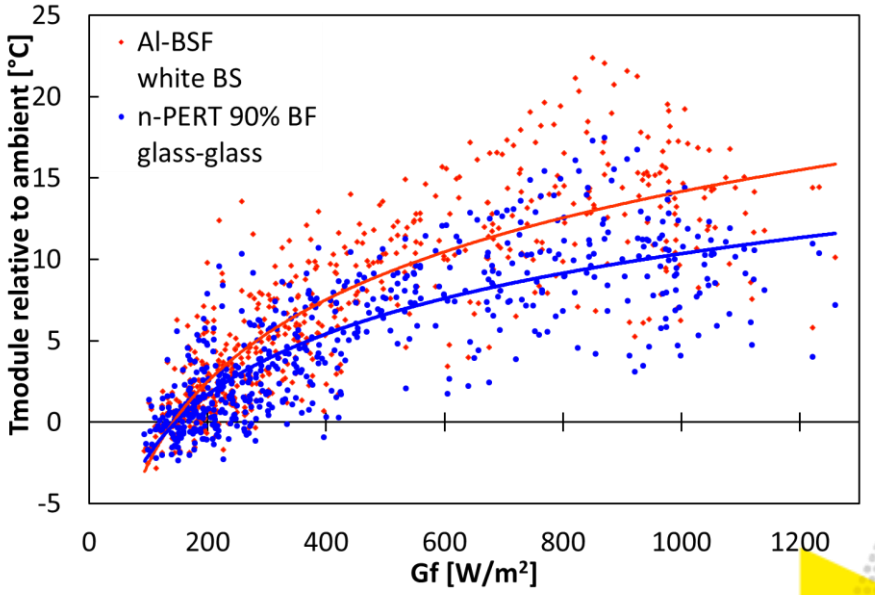




- Al-BSF cells in all laminates ΔT=14-16 K
- Bifacial cells with backsheet ΔT=14 K, in glass-glass laminates ΔT=10 K

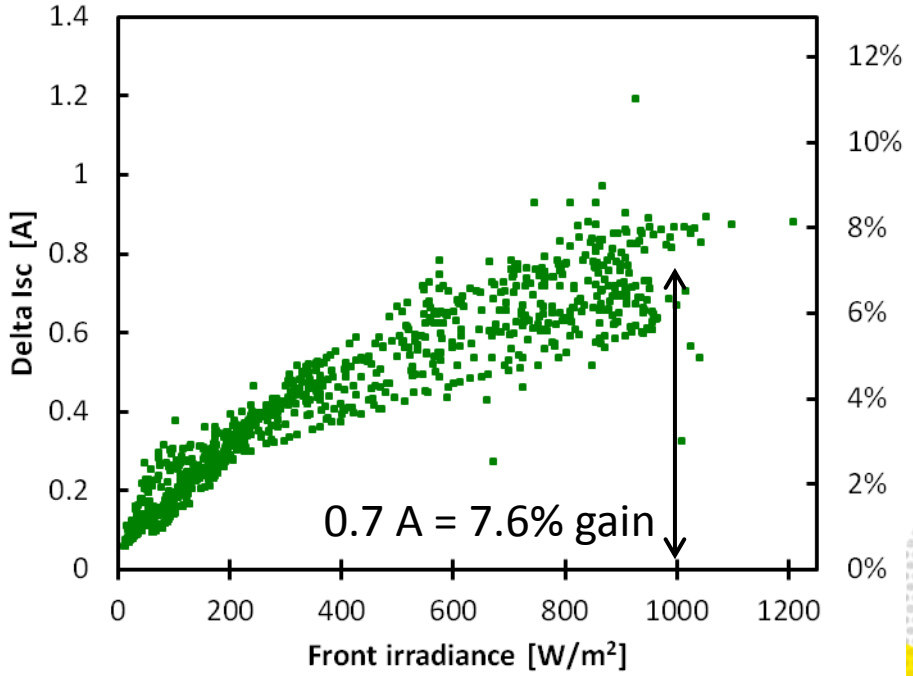
Summary single cell laminates

- Effective heating depends on
  - Bifaciality cells
  - rear panel properties
- Al-BSF in white BS laminate has ΔT=14 K
- n-PERT in glass-glass laminate has ΔT=10 K
- Glass-glass laminates have lower temperature than expected from heating analysis



Bifaciality leads to higher current

- Full size modules, rooftop set-up with low albedo (roof edge)
- Bifacial Isc gain is relatively stronger at low irradiance



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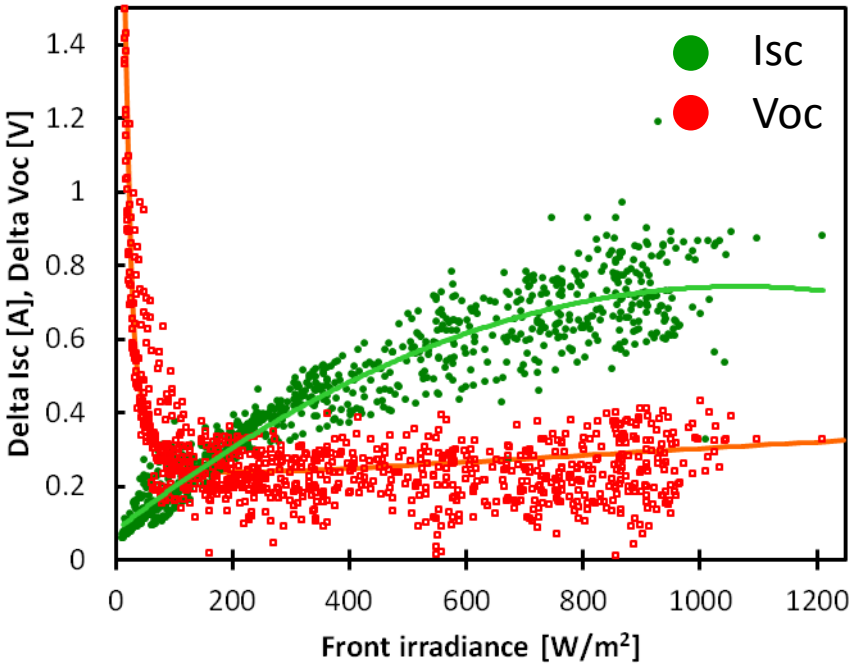
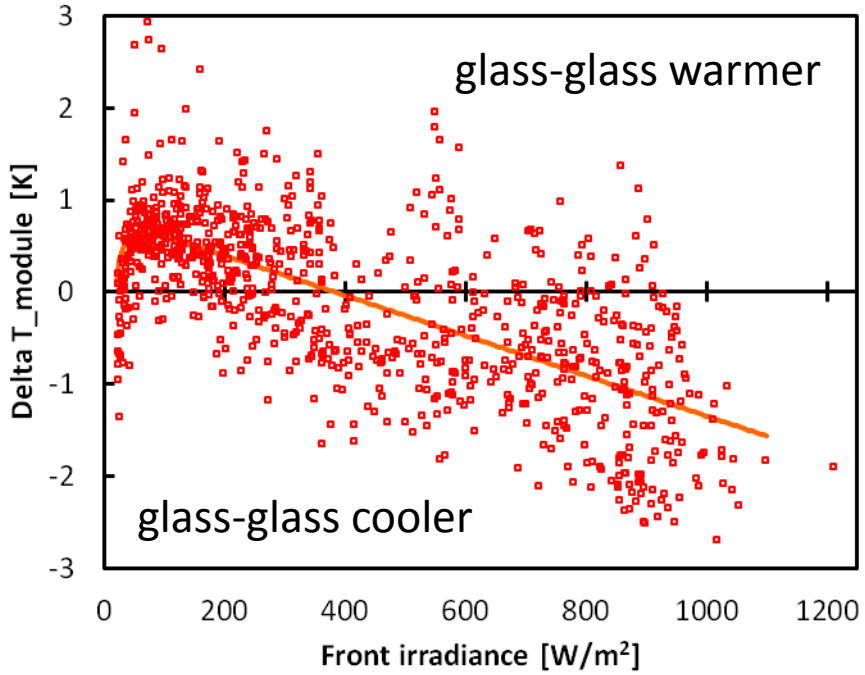
Bifaciality leads to higher current and also effects voltage, in two ways

- Full size modules, rooftop set-up with low albedo (roof edge)
- Bifacial Isc gain is relatively stronger at low irradiance
- At lowest irradiance bifacial Voc is larger due to bifacial irradiance
- At high irradiance bifacial Voc stays higher due to lower module temperature



Bifacial gain in current/power does not lead to significant heating of bifacial modules

- At low irradiance, bifacial gain leads to limited extra warming of modules
- At high irradiance, bifacial modules become cooler



Conclusions

Research question:

- Bifacial cells -> higher output (not a question here!)
- Increased (parasitic) heating? -> temperature up? -> lower output?

My answers:

- At low irradiance <100 W/m^2: small temperature increase for glass-glass laminates observed but Isc and Voc increases much higher
- At high irradiance: bifacial glass-glass laminates are observed to have lower temperature

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