High performance double-glass bifacial PV modules through detailed characterization

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Outline

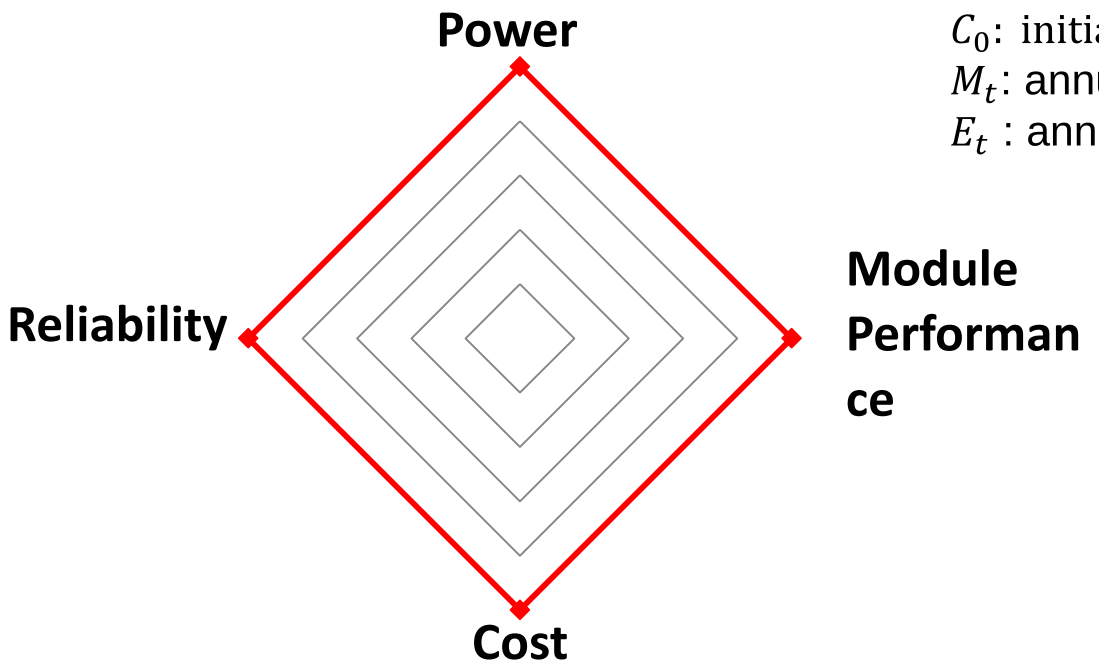
- Introduction
- Loss characterization in double-glass bifacial PV modules
  - Optical loss
  - Resistive loss
- Approaches for high performance double-glass bifacial module development
  - Half-cut cell and multi-busbar cell modules
  - Bifacial modules with IR reflective coating
  - Bifacial modules with selective reflective coating

Introduction

- Levelized cost of electricity (LCOE)
- Cost/kWh

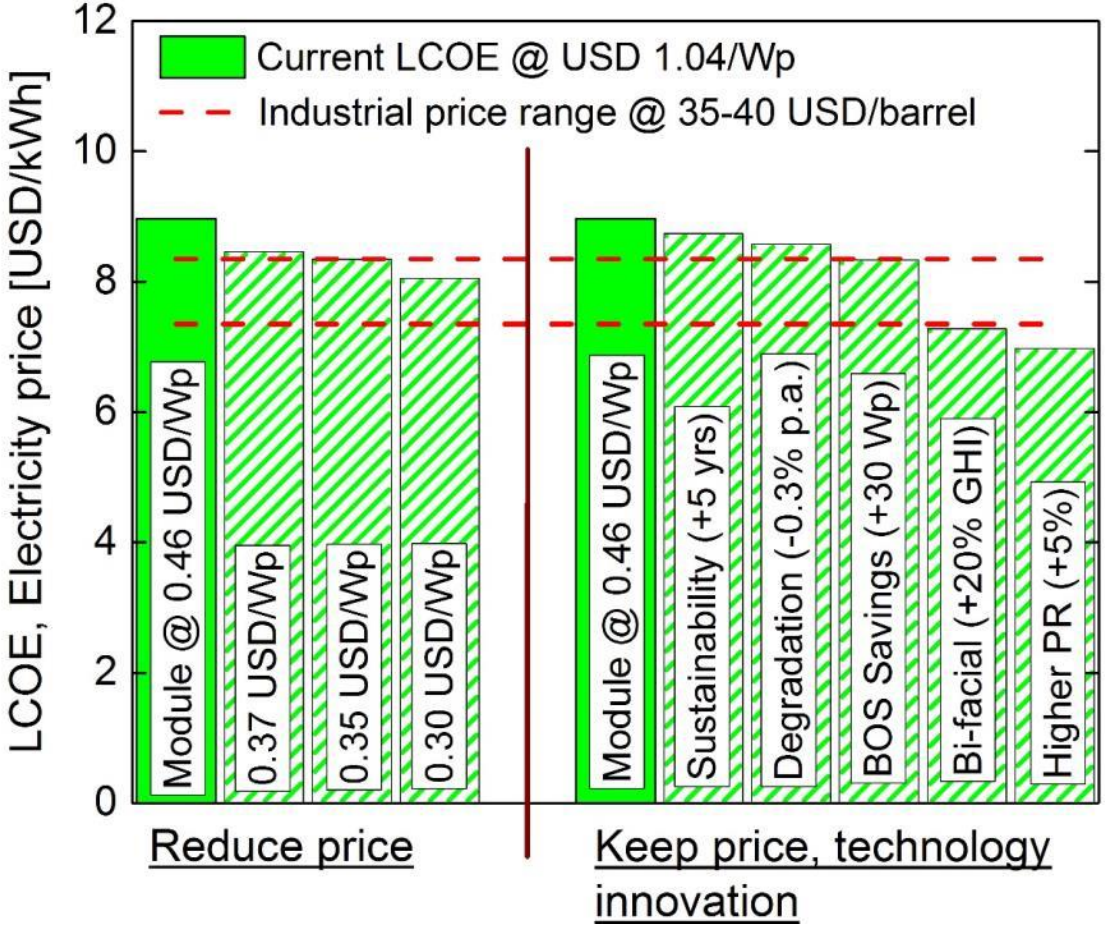
$$LCOE = \frac{Lifecycle\ cost}{Lifetime\ electricity\ generation} = \frac{C_0 + \sum_{t=1}^{n} \frac{M_t}{(1+i)^t}}{\sum_{t=1}^{n} \frac{E_t(1-d)^t}{(1+i)^t}}$$

C_0: initial capital cost
M_t: annual O&M cost
E_t : annual energy produced



LCOE study of PV in Singapore

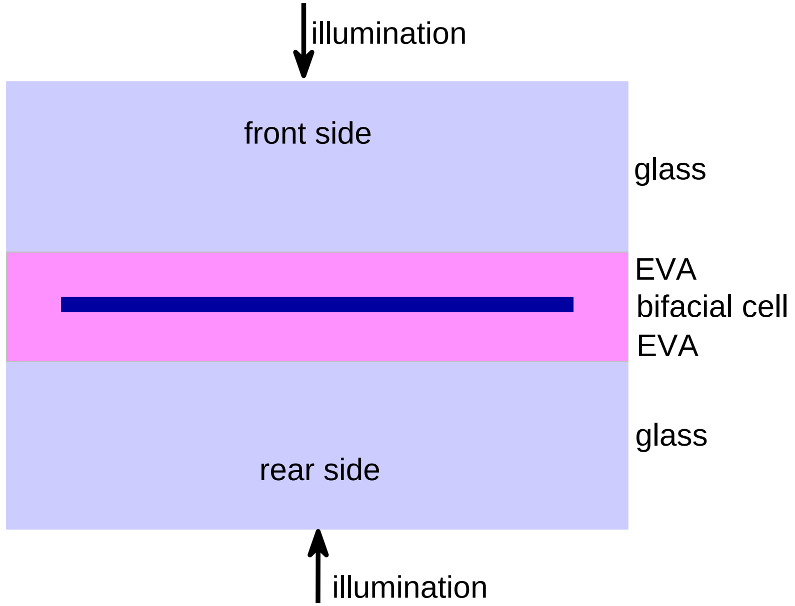
Grid parity can be achieved either with aggressive price or innovative technology strategy

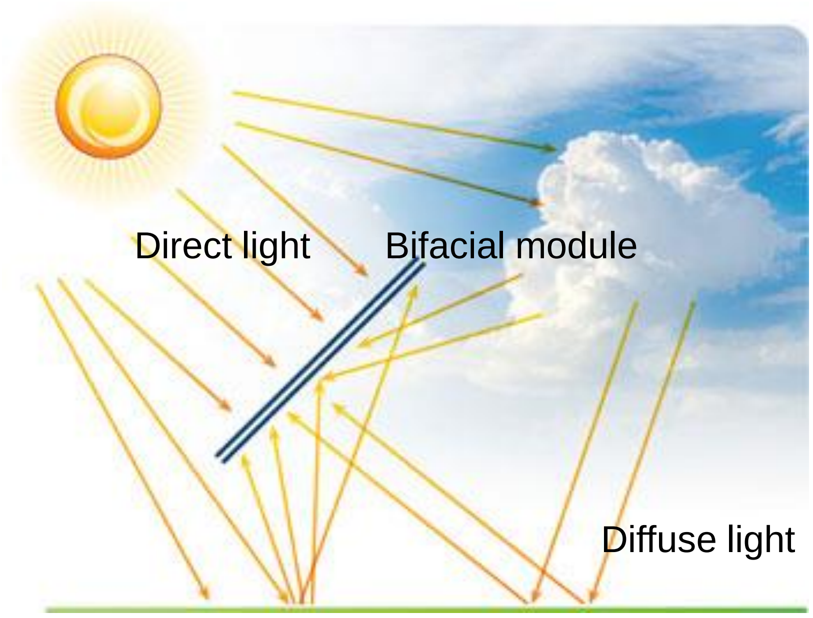


GHI = Global Horizontal Irradiance, PR = Performance Ratio

Double-glass bifacial PV modules

- LCOE can be reduced through
  - Higher energy yield (10-20% gain is achievable in outdoor conditions by using Albedo from surroundings)
  - Improved reliability
- Promising future module technology





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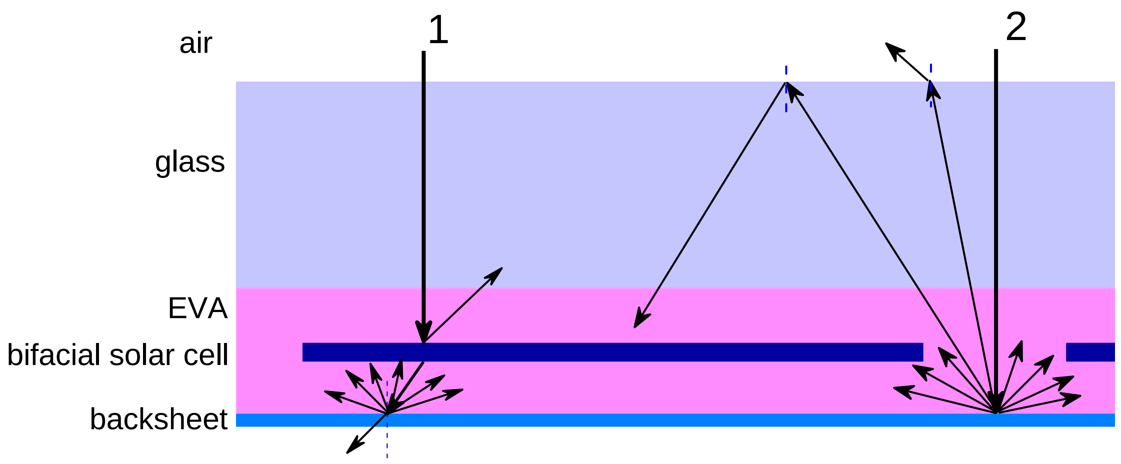
Module structures using bifacial cells

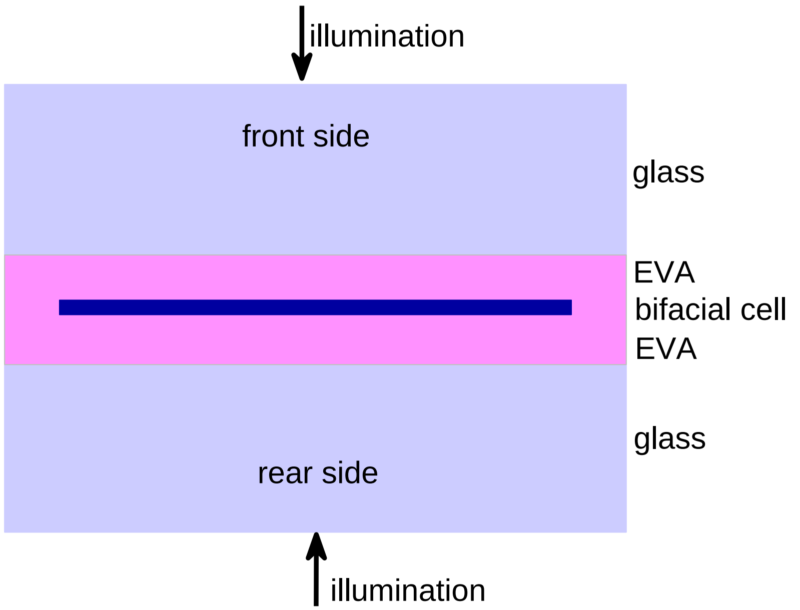
Glass/backsheet

- ❑ Power gain under STC
- ❑ Sellable module power (STC measurements)



Double-glass

- ❑ More energy generation in outdoor conditions by using Albedo from surroundings



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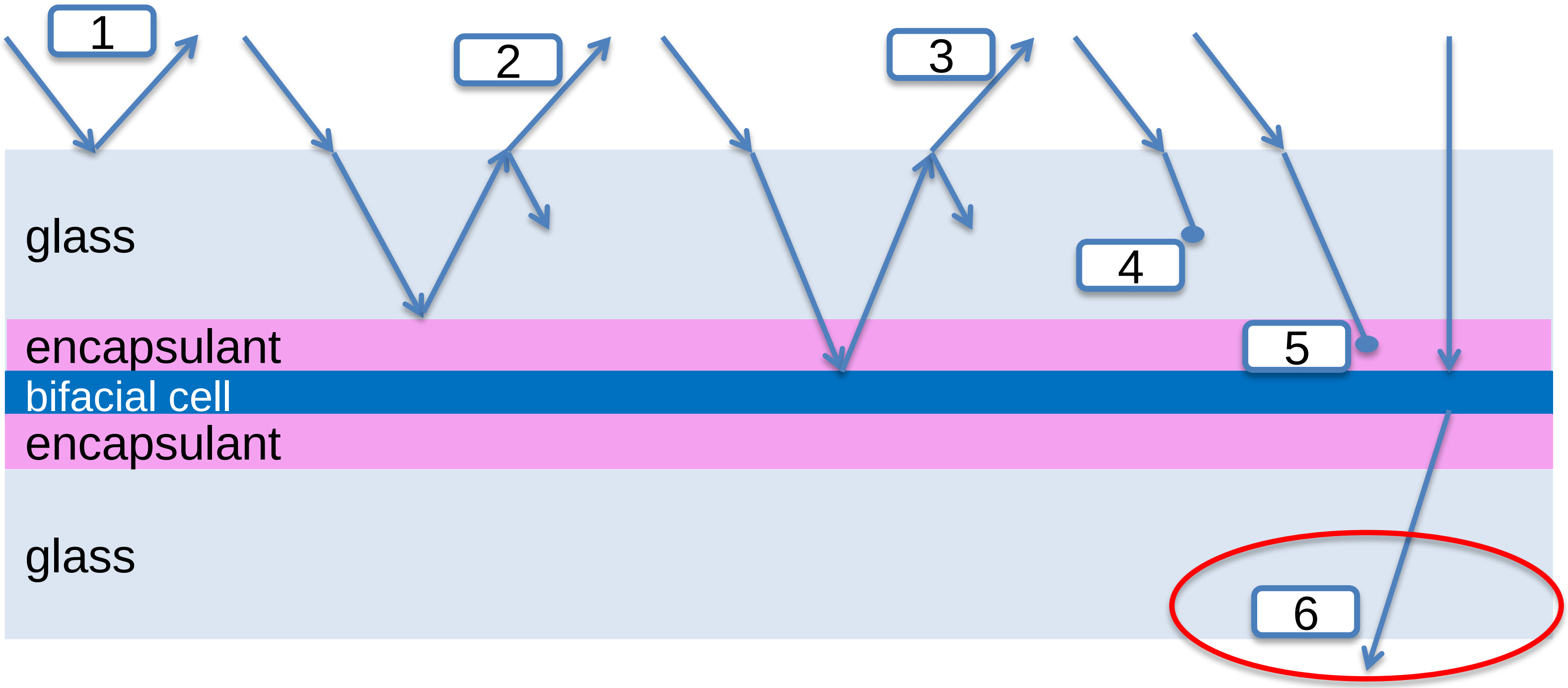
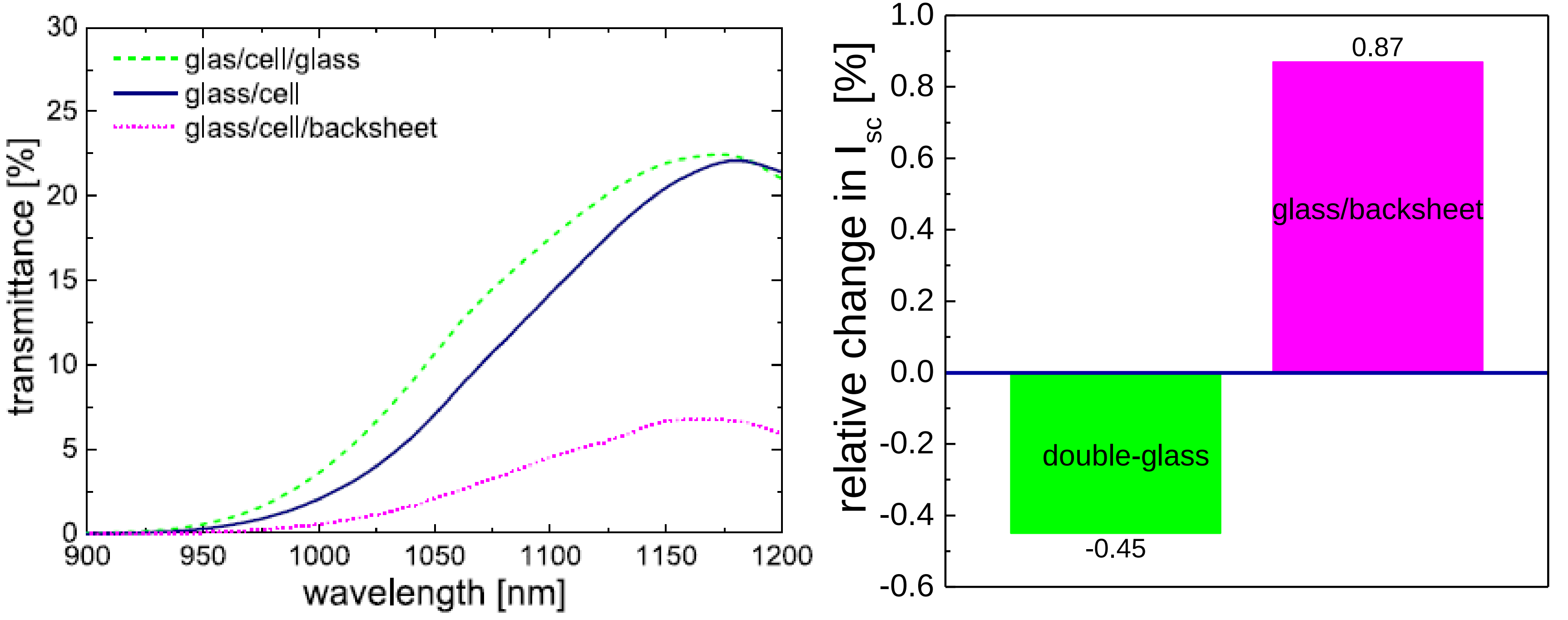
Optical loss: bifacial cell transmittance

- Reflection (1-air-glass, 2-glass-encapsulant, 3-encapsulant-cell) and Absorption (4-glass, 5-encapsulant): **same as standard glass/backsheet modules**
- Transmission (6-through bifacial cell and rear glass)



Optical loss: bifacial cell transmittance



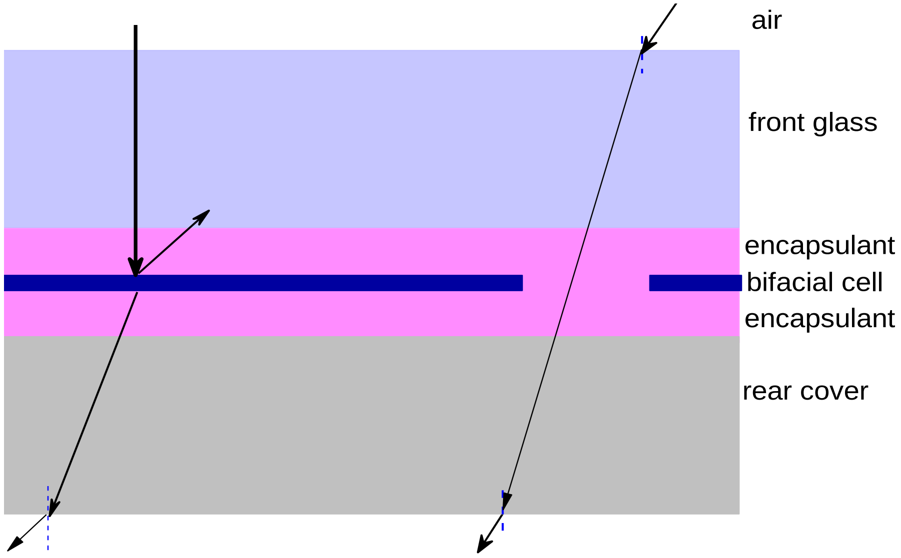
- Significant amount of near infrared light passes through bifacial cells.
- Double-glass structure shows a loss of ~ 1.30% compare to the glass/backsheet structure under STC measurements.

J. P. Singh, et al. "Comparison of Glass/glass and Glass/backsheet PV Modules Using Bifacial Silicon Solar Cells," *IEEE Journal of Photovoltaics*, vol. PP, pp. 1-9, 2015.

Optical loss: cell-gap area

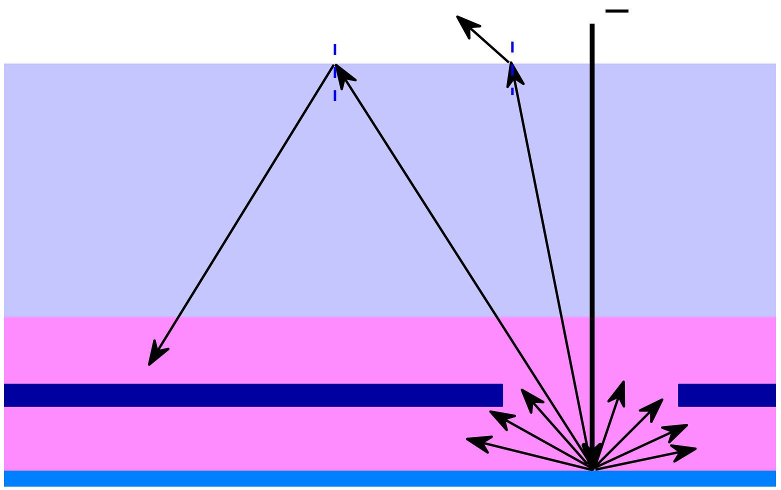
Double-glass structure:

- ❑ No current contribution due to the cell-gap region



Glass/backsheet structure:

- ❑ Current gain due to the static concentration effect of the light incident on the cell-gap region



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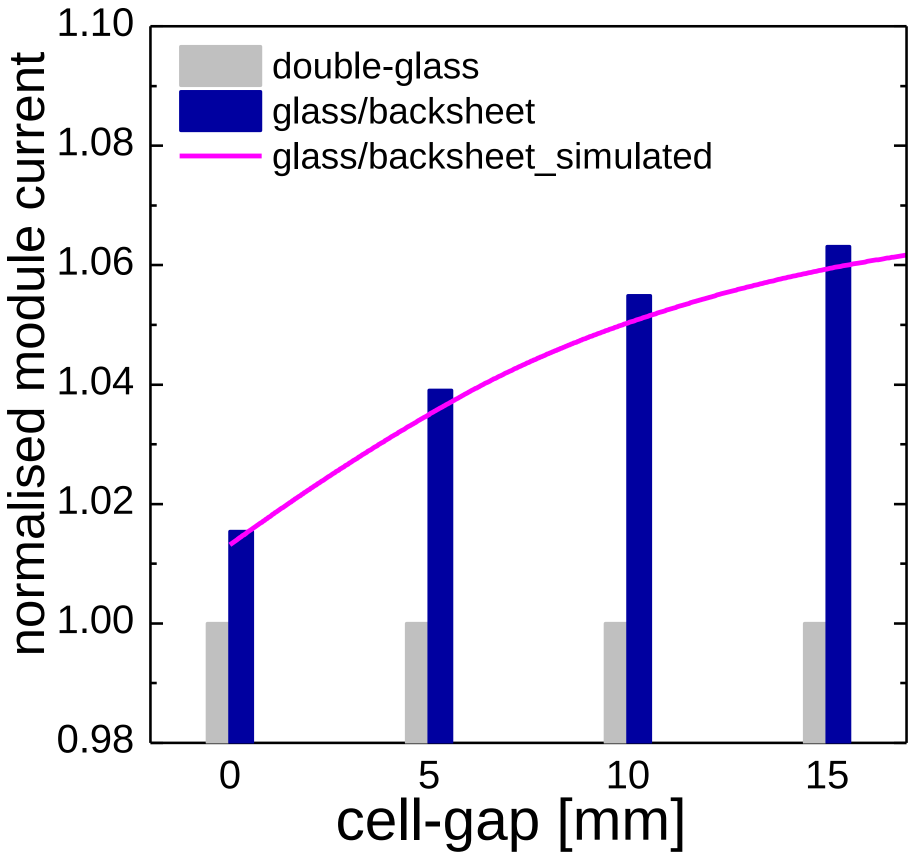
Optical loss: cell-gap area

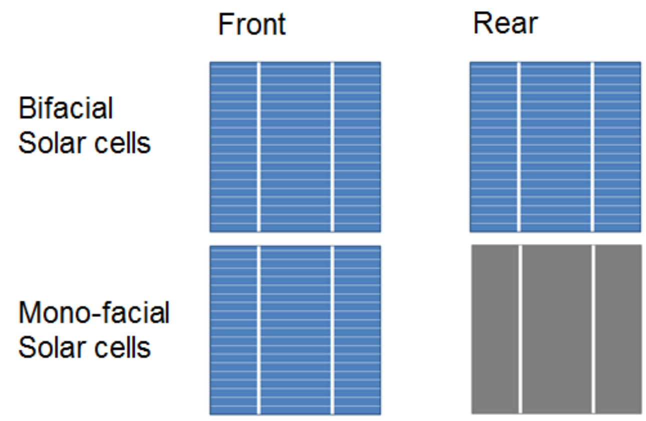
- Double-glass bifacial modules show 3-4% power loss compared to glass/backsheet modules
- The loss depends upon the cell-gap

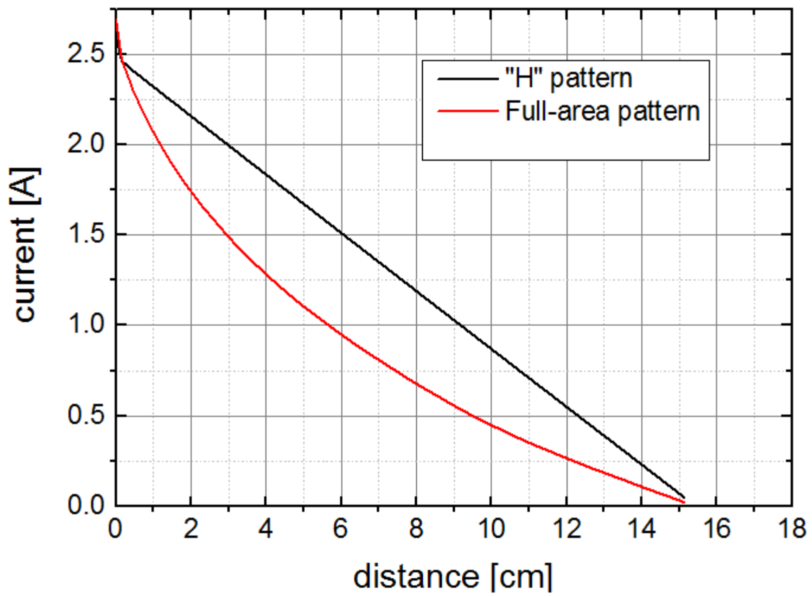


J. P. Singh, et al. "Comparison of Glass/glass and Glass/backsheet PV Modules Using Bifacial Silicon Solar Cells," *IEEE Journal of Photovoltaics*, vol. PP, pp. 1-9, 2015.

Resistive loss in stringed bifacial cells

- Mainly caused by the current flowing through the ribbons
- **Impact of resistive losses is more on bifacial modules**
  - Current flow pattern is different for monofacial and bifacial cells
  - High current generation due to albedo
  - Higher resistive loss compared to monofacial





S. Guo, et, al, "Two-dimensional current flow for stringed PV cells and its influence on the cell-to-module resistive losses," *Solar Energy*, vol. 130, pp. 224-231, 2016

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Reducing resistive losses

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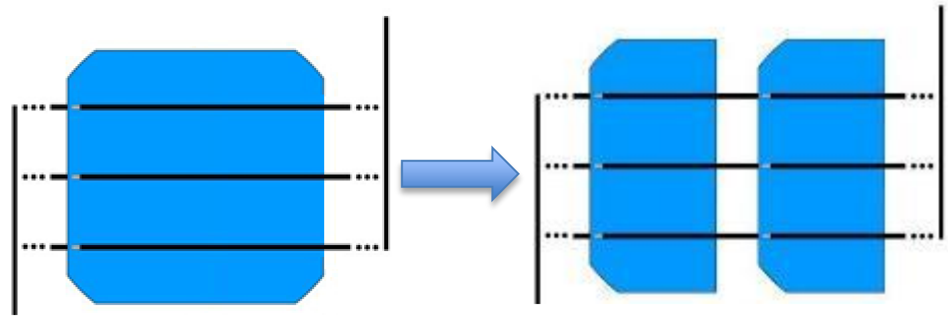
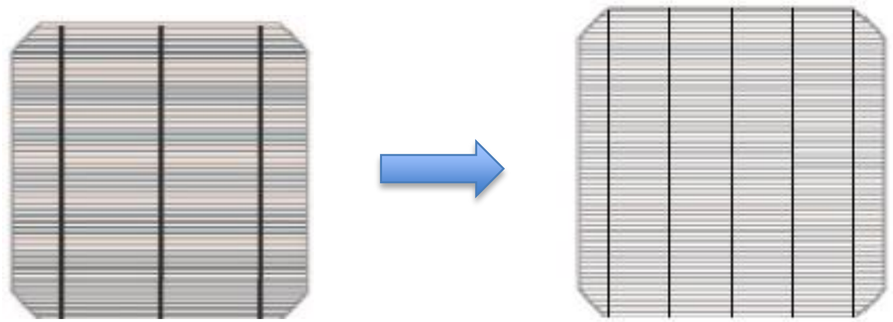
- Halved-cell modules



- Multi-busbar modules



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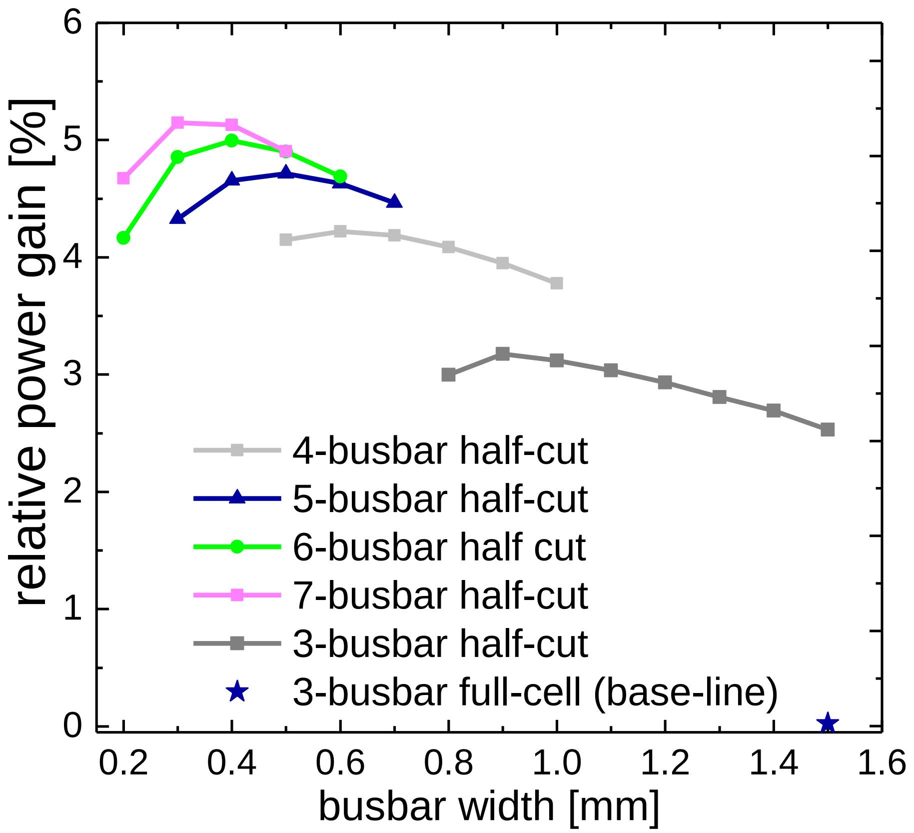
Reducing resistive losses

- Combining the half-cut and multi-BB concepts, ~ 4% power gain is achievable compared to standard 3-BB full-cell modules.



Improving optical performance: reduce module transmittance loss

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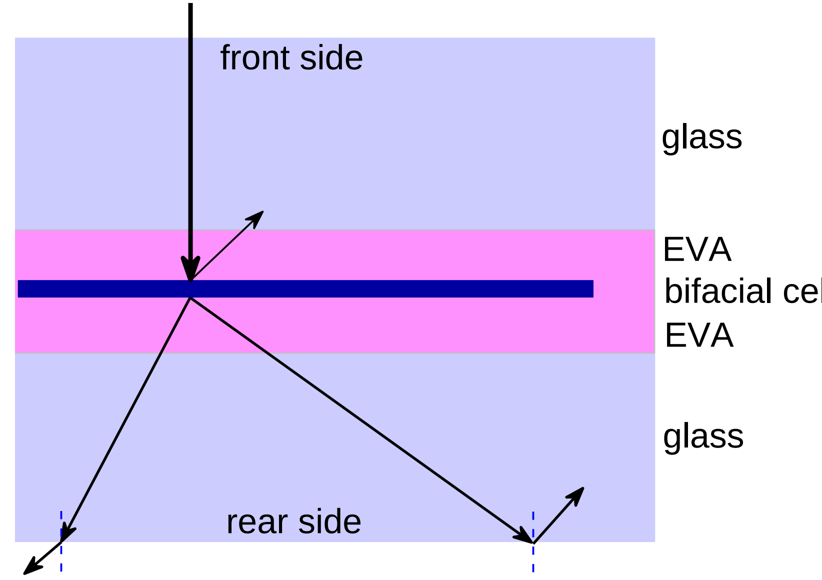
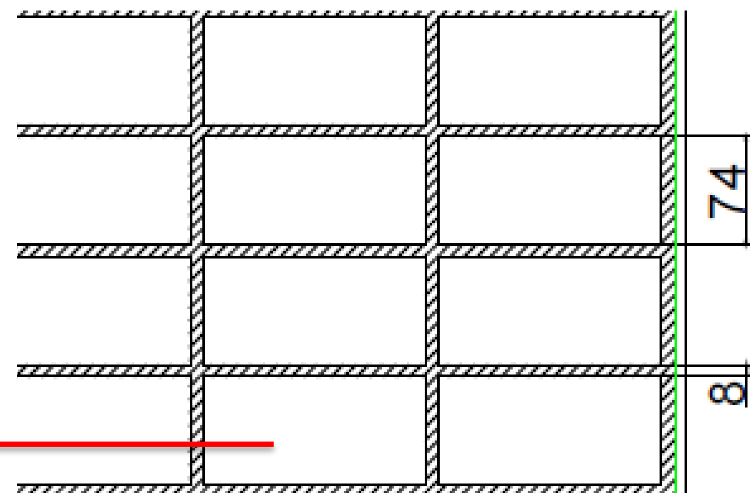
- ❑ Minimize the losses which occurs due to bifacial cell transmittance



Solution

- ❑ Using IR reflective coating on the rear side glass
- ❑ Reflective coating only reflects IR and is transparent to other spectrum
- ❑ Maintain the bifacial performance



IR reflective coating

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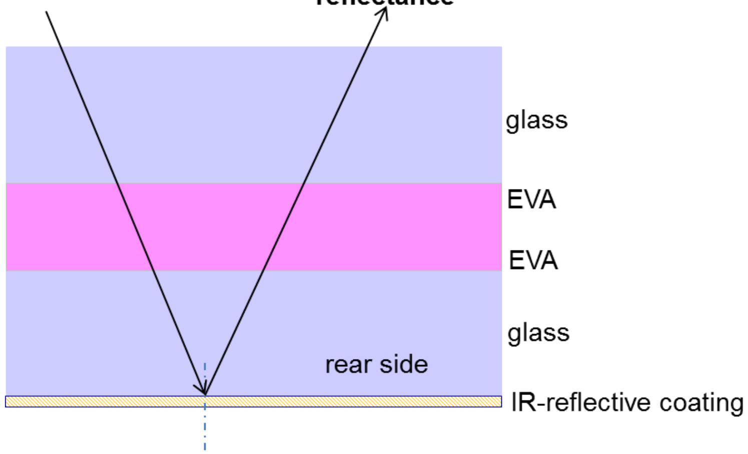
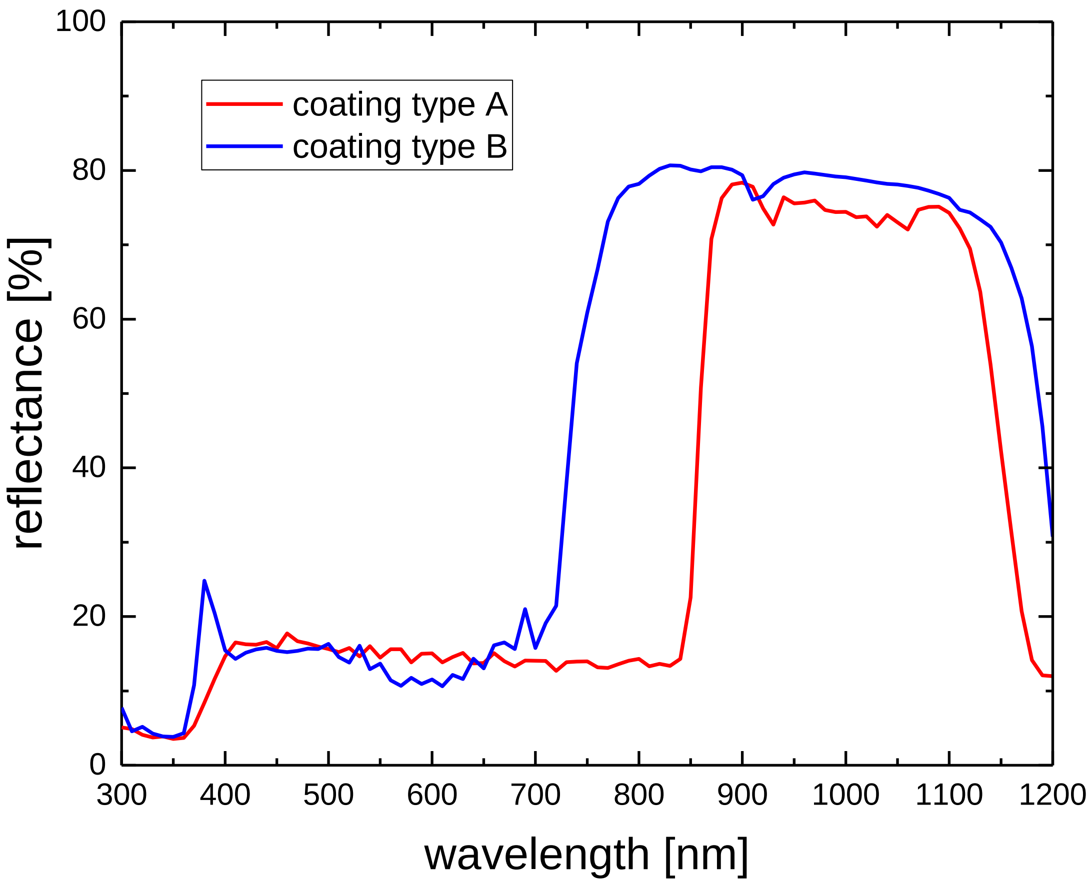
Evaluation of IR reflective coatings: Reflectance

- Reflectance measurement of IR reflective coatings





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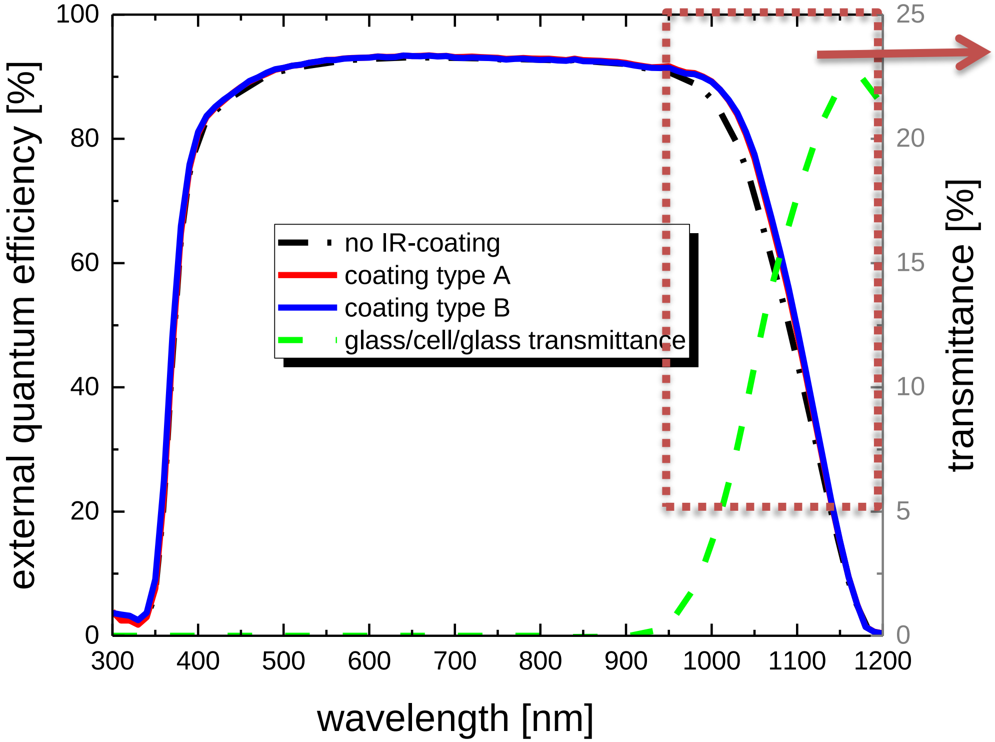
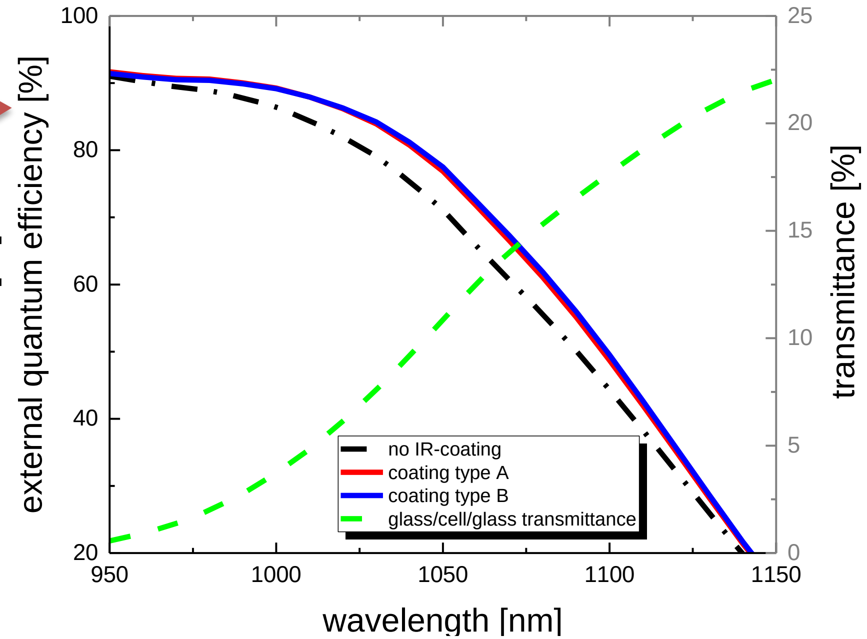
Evaluation of IR reflective coatings: External Quantum Efficiency (EQE)

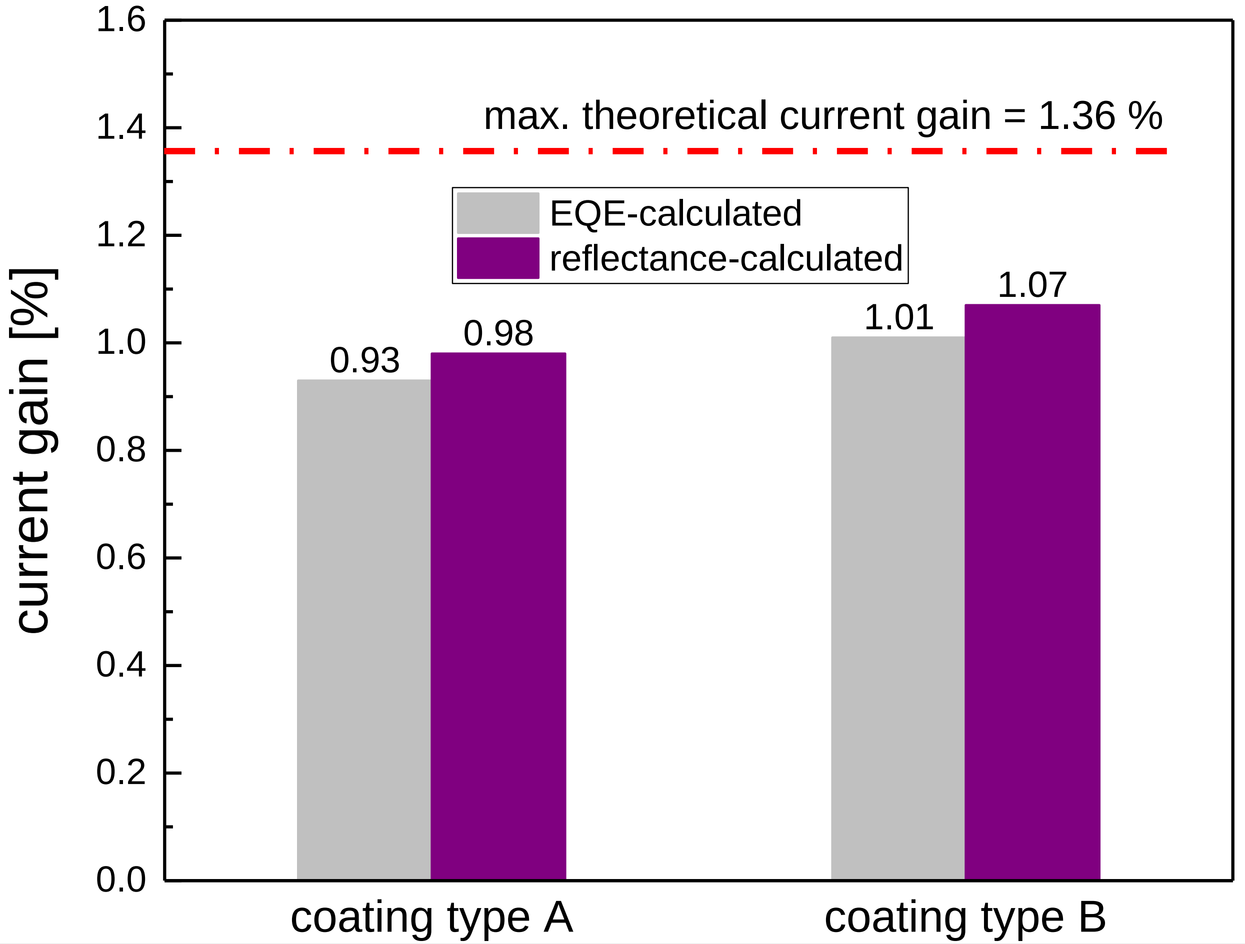
- EQE measurements with and without reflective coating
- Current gain contributed by IR reflective coating is calculated using the bifacial cell transmittance, cell EQE & reflectance of coating





Current gain with IR reflective coating

- *double-glass (without coating) is the reference module
- calculated current gain in the range of 1 %



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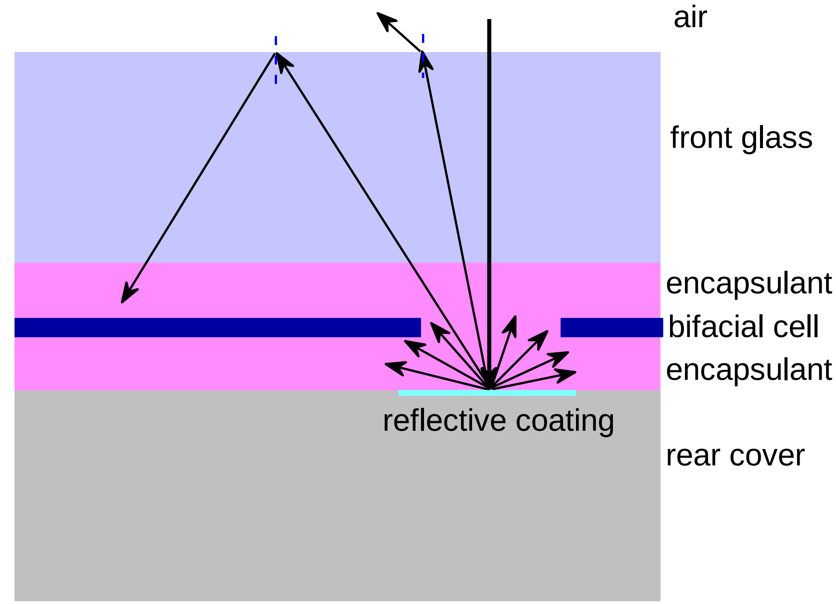
Improving optical performance: reduce cell-gap loss

- ❑ Minimize the losses which occurs due to double-glass design

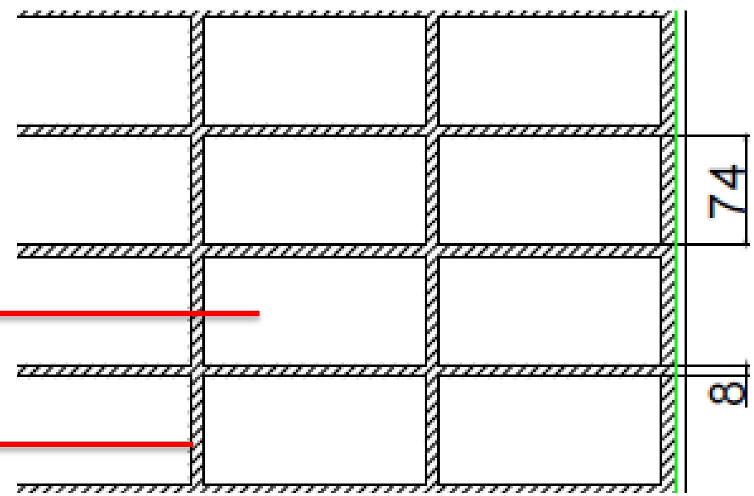
Solution

- ❑ Using reflective coating on the rear side glass
- ❑ To maintain the bifacial performance, reflective coating is applied in the cell-gap region only



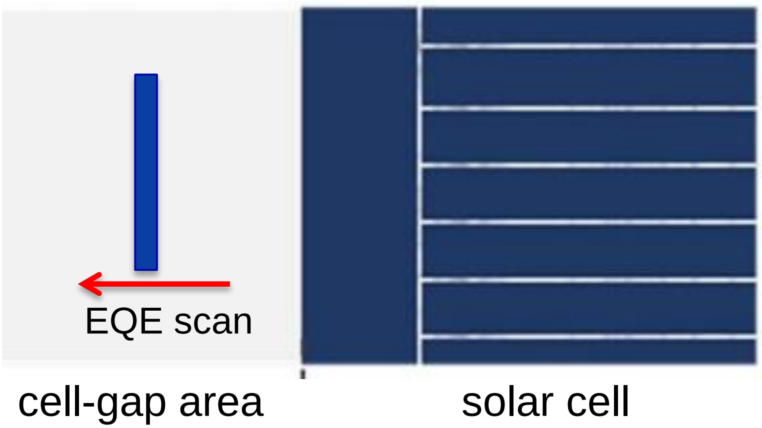
IR reflective coating (cell)

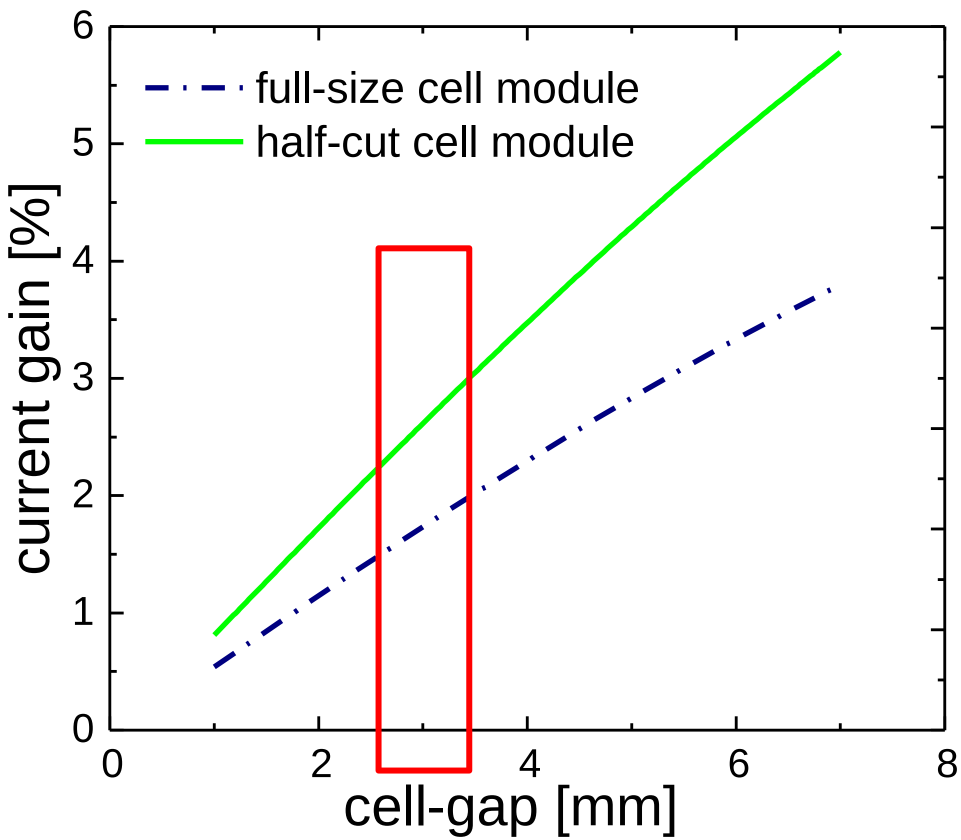
reflective coating (cell-gap)



Current gain from cell-gap area with reflective coating

- Current gain for different cell-gap is calculated using the EQE-line scan and cell-gap area information
- ***double-glass (without coating) is the reference module**





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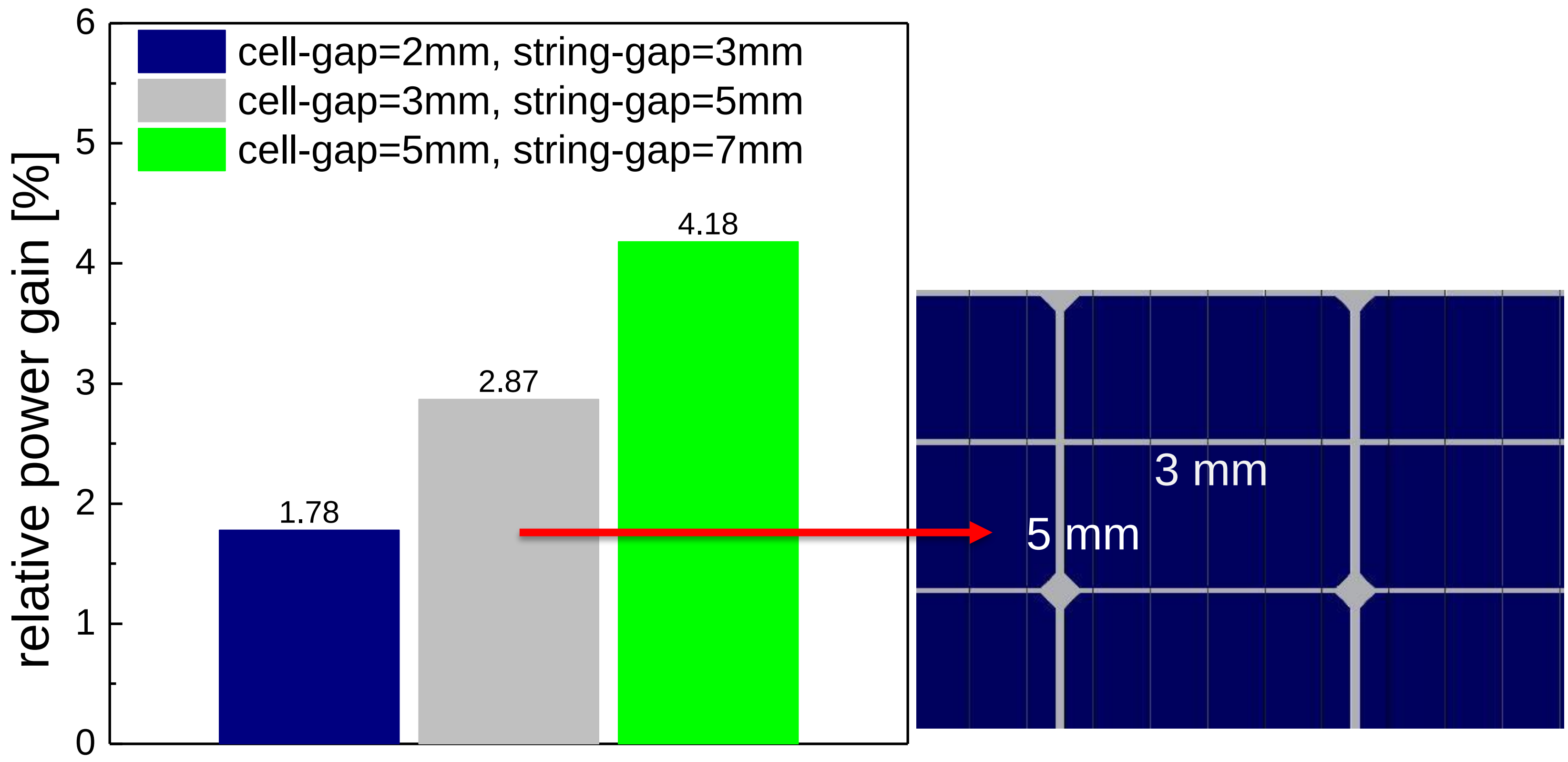
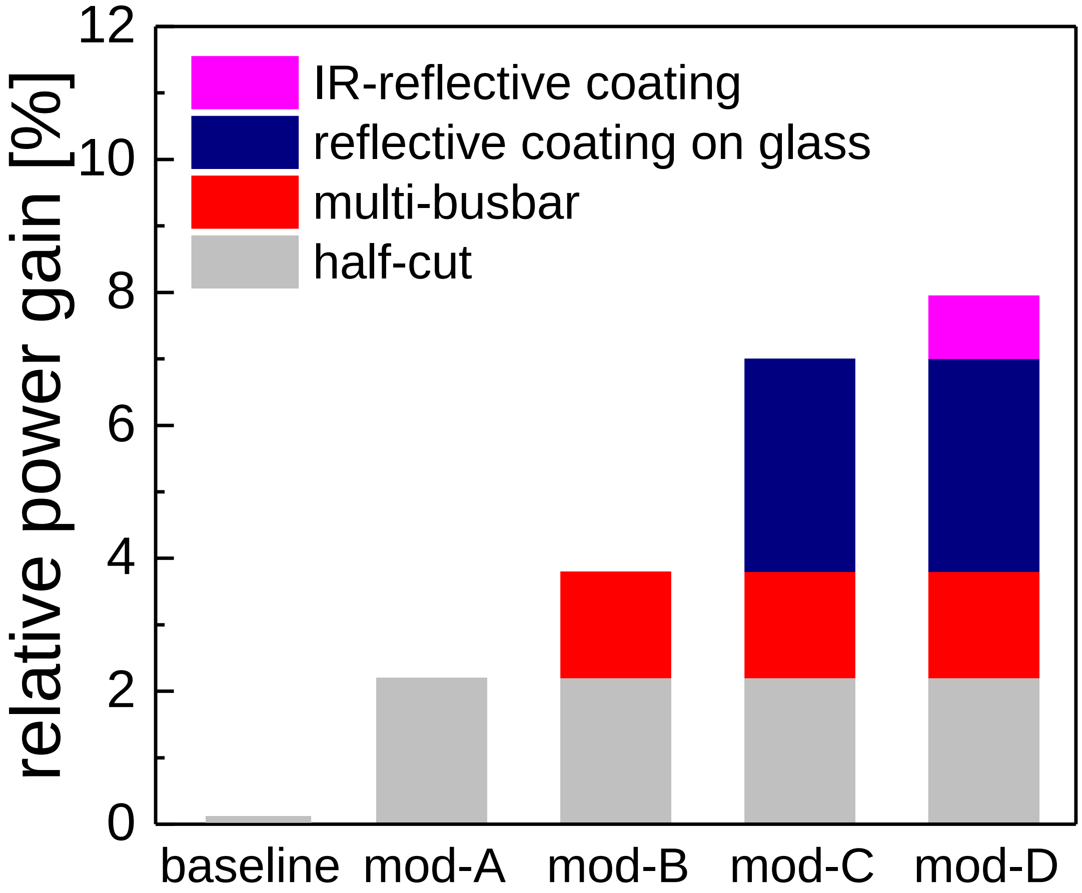
Current gain from cell-gap area with reflective coating: experiments

- Mini-module with (9-half-cut cells) were fabricated to measure the current gain for different cell-gaps.
- ***double-glass (without coating) is the reference module**



Power gain for various module designs



- ***Baseline: standard double-glass, bifacial, 3-busbar, full-size cell module**
- Cell-gap= 3 mm, string-gap= 5 mm

Double-glass bifacial PV module made @ SERIS

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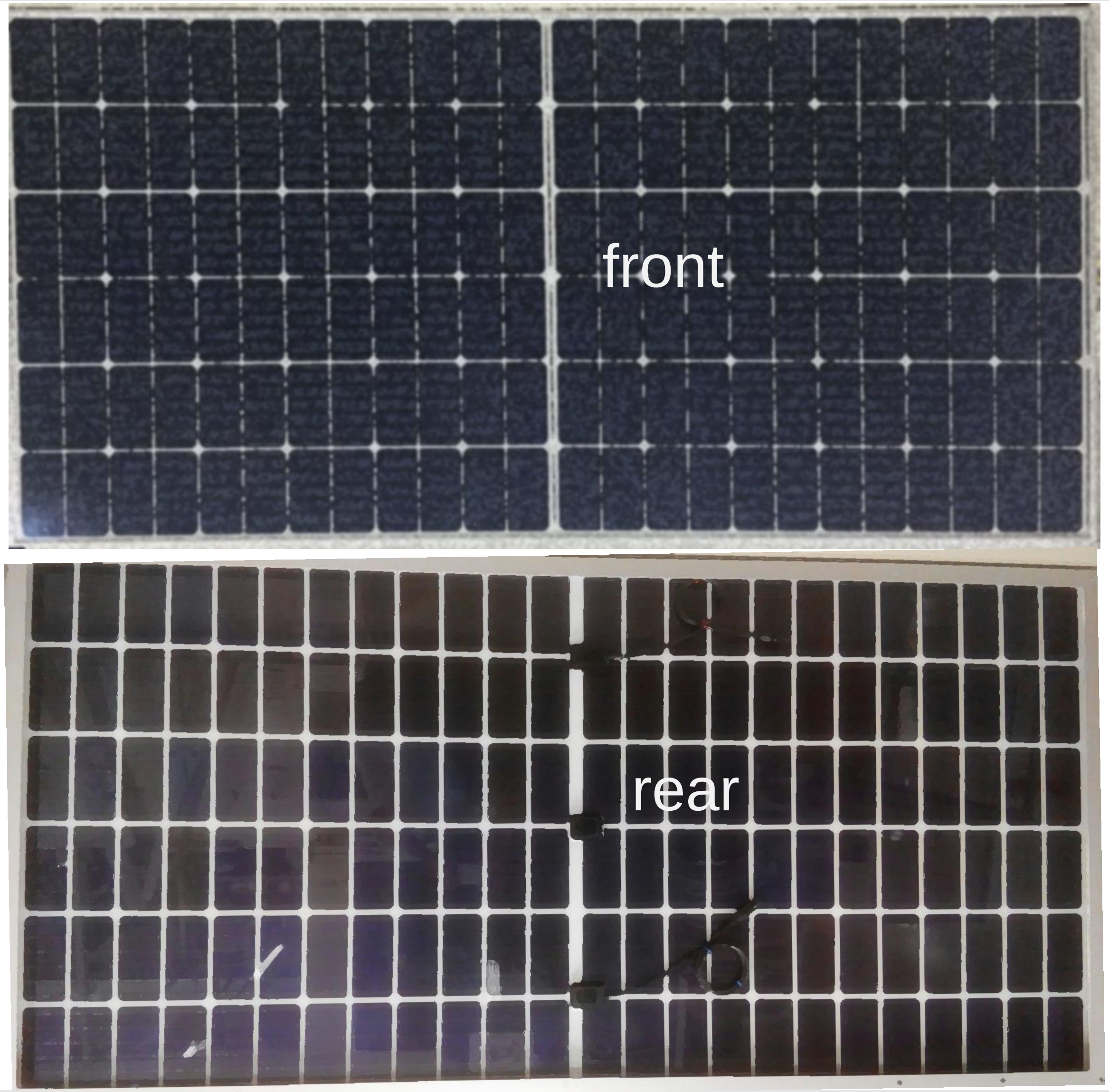

- Half-cut
- Multi-busbar
- Selective reflective coating (rear side)

Thank you for your attention!

More information

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