This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 792059

goPV

Oct. 27th

PV Modules: Market & Technology Trends

(10:00-12:00)

GLOBAL OPTIMIZATION OF INTEGRATED PHOTOVOLTAIC SYSTEM FOR LOW ELECTRICITY COST

Session Contents

1. From solar cells to modules (Olatz Arriaga)
2. Materials and processes used in solar module manufacturing (Luca Gnocchi)
3. Targeting PV module service lifetimes of 35+ years (Dr. Alessandro Virtuani)

PV Modules: Market & Technology Trends

Session Contents

1. **From solar cells to modules (Olatz Arriaga)**
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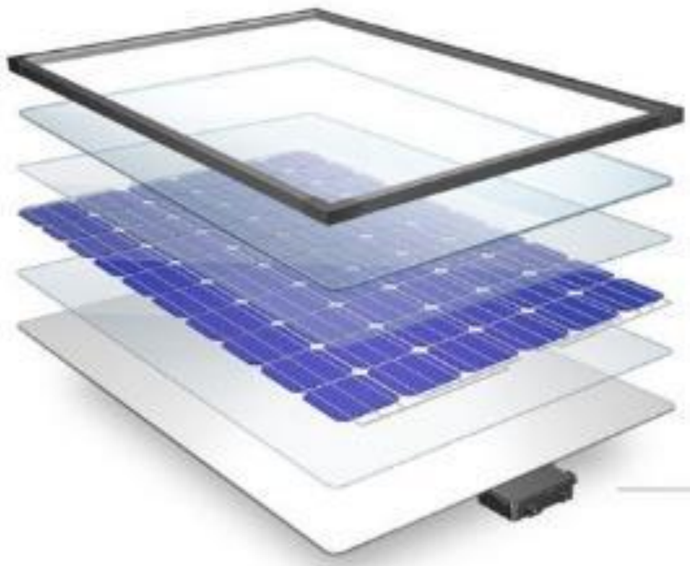
3. Targeting PV module service lifetimes of 35+ years (Dr. Alessandro Virtuani)

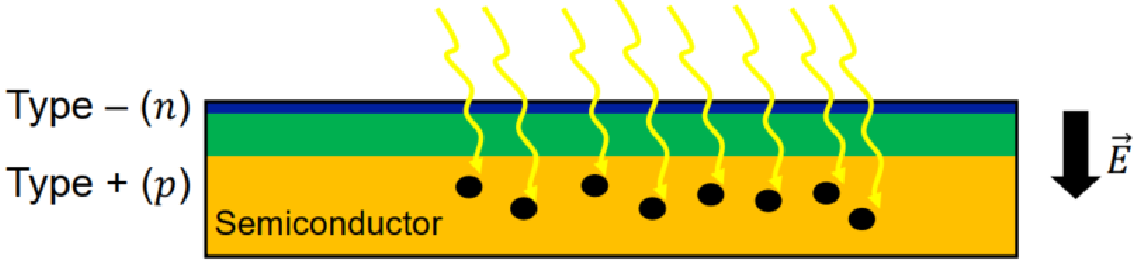
1. From solar cells to modules

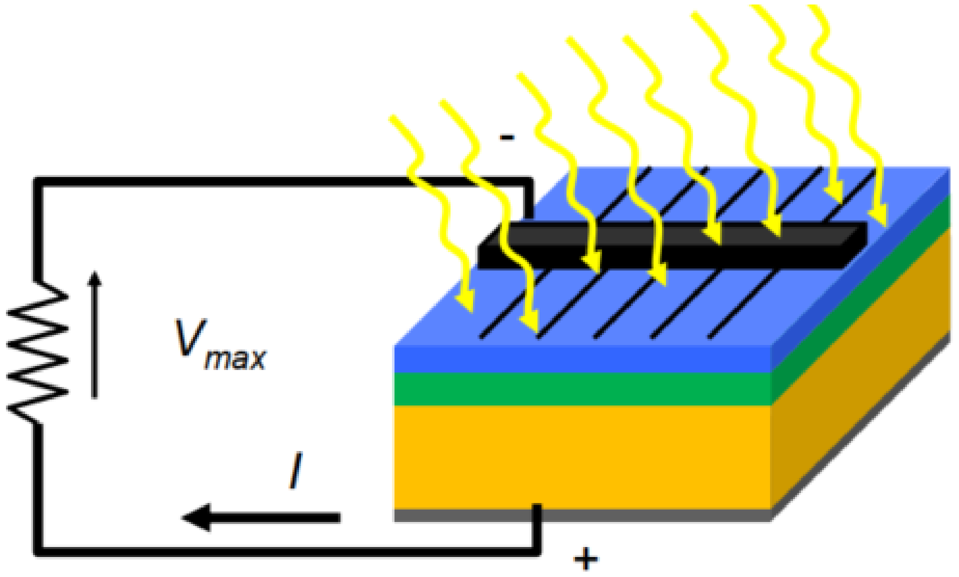


1. From solar cells to modules

What is a solar cell?

p-n junction





- Intrinsic (pure) **semiconductor** material (e.g. Si).
- Doped with impurities to become conductor $\rightarrow +(\mathrm{p})$ o – (n) charges transporting the current
- **Under light** $\rightarrow$ absorption of **photons** if $\mathrm{hv} > \mathrm{E_g}$ ($\mathrm{E_g}$: semiconductor bandgap).
- Photons absorbed in p-zone transfer their energy to electrons (in n-zone to holes).
- Photogenerated carriers move towards the junction and cross it.

Metallic contacts extract the current

1. From solar cells to modules

PV Technology Trends

Market

Crystalline silicon
Mono and multicrystalline
Status: main market share

Thin films
CIGS, CdTe
Status: 3-5% market share

III-V solar cells
Space application

Concentrator technologies

Status: failed market entrance
New innovative concepts

Other technologies
Organic-Polymer, Dye sensitized, nano-inorganic
Status: niche application, failed market entrance
Perovskite: R&D with challenges

Novel PV concepts
Quantum dots, intermediate band…
Status: attempt of demonstration

1. From solar cells to modules

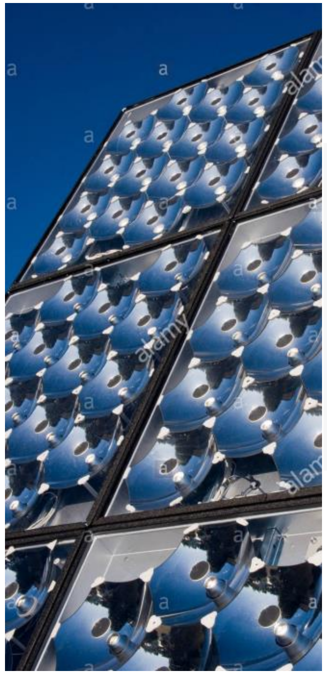
Crystalline Silicon (c-Si)

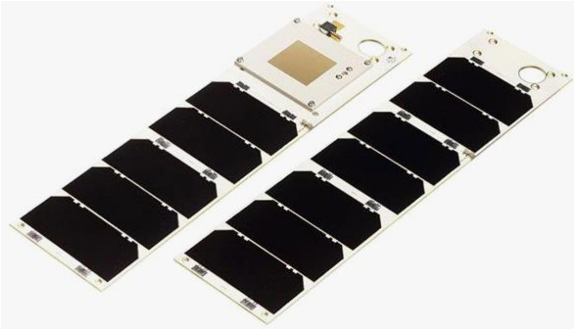
Wafer based (bulk semiconductor)
- Processing of wafers
- Series connection of individual solar cells

Thin film

- Deposition on large area substrate
- “Monolithic series integration” of the cells

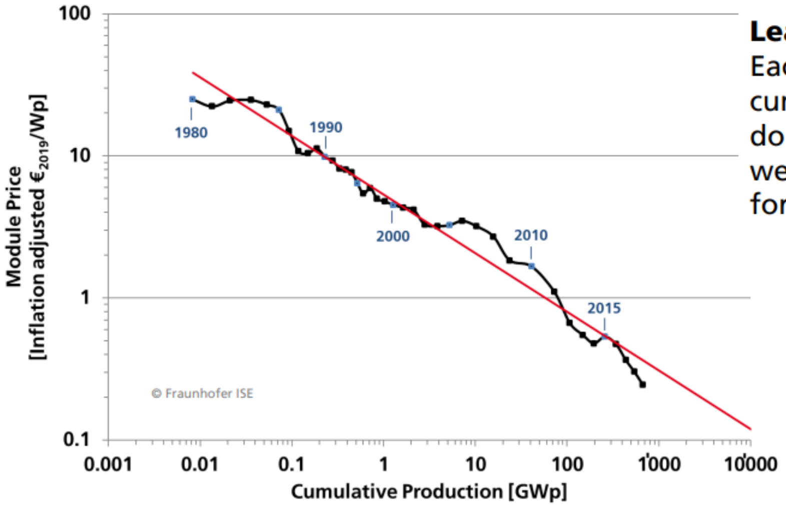
III-V multi-junction





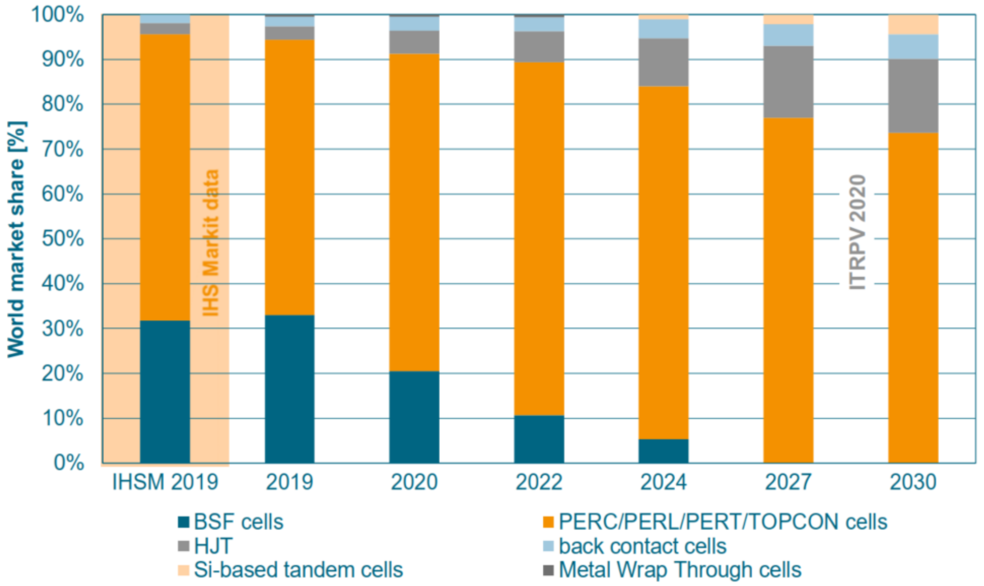
- Grown epitaxially on crystalline wafers
- Developed for space applications → very costly
- Used in concentrated PV (CPV)

1. From solar cells to modules



Learning Rate:
Each time the cumulative production doubled, the price went down by 25 % for the last 39 years.

Fraunhofer ISE: Photovoltaics Report (2019)



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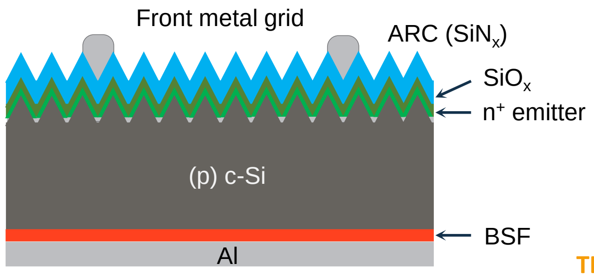
- **1980-1990's** → high performance industrial cells (Si from microelectronics research).
  - ➢ Challenges: reduce cost by a factor or 20-30.
- **2000-2010** → strong market development → high demand of PV modules → Si shortage
- **2010 decade** → production moving to China → lower production costs, reduction in module prices, lower electricity prices

Aluminium Back Surface Field (Al-BSF)



1. From solar cells to modules

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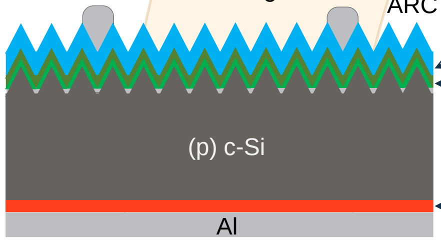
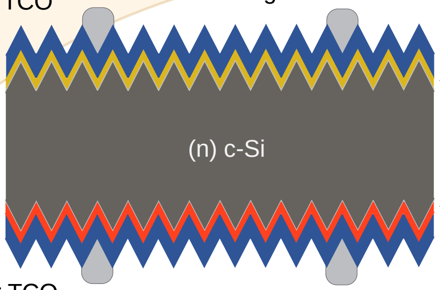


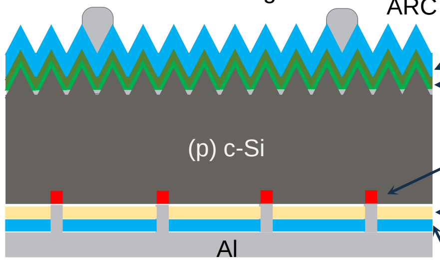
Low Temperature Process

Silicon Heterojunction (SHJ)

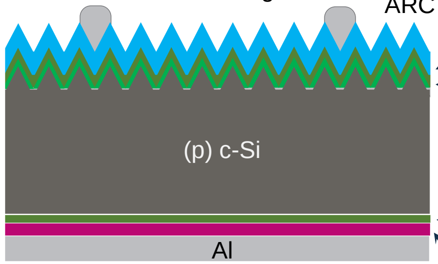


High Temperature Process

Passivated Emitter and Rear Contact (PERC)

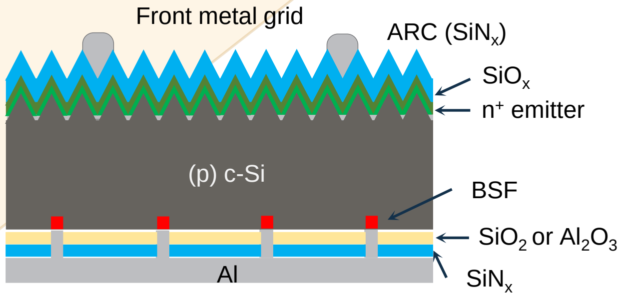


High Temperature Passivating Contact (HTPC)



1. From solar cells to modules

Passivated Emitter and Rear Contact (PERC)

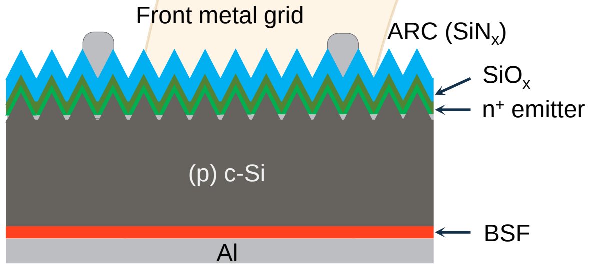


Challenges:

- **Optical losses** → reflection of photons at rear surface)
- **Recombination losses** → at metallic contact
- **Ohmic losses** → high series resistance at interfaces

- Better passivation (rear surface)
- ↓ Optical losses
- Similar manufacturing
- High temperature processing

Aluminium Back Surface Field (Al-BSF)



1. From solar cells to modules

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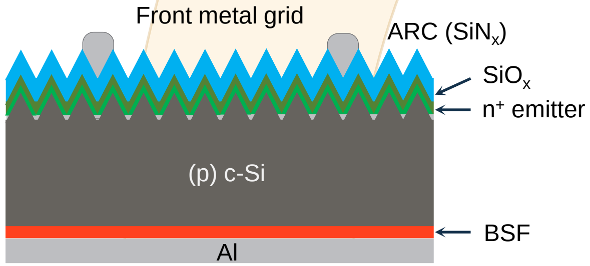

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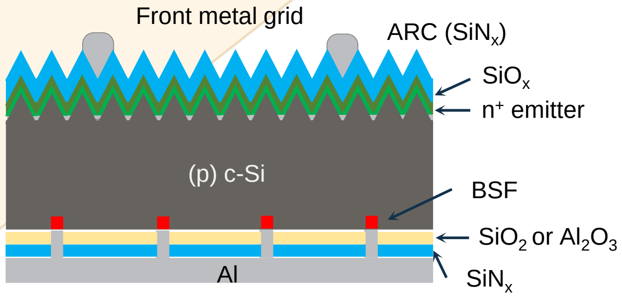
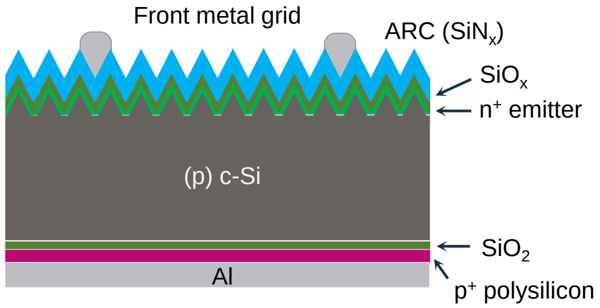


- Better passivation (rear surface)
- ↓ Optical losses
- Similar manufacturing
- High temperature processing

High Temperature Passivating Contact (HTPC)



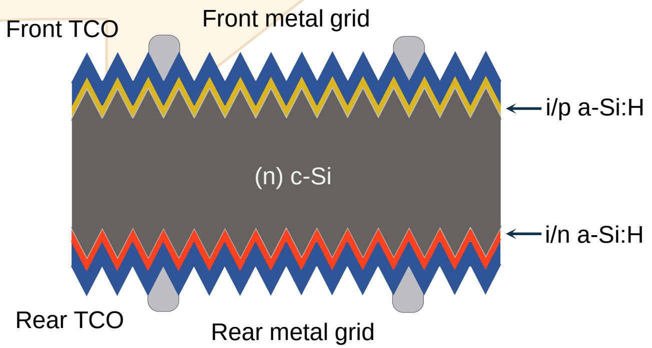
- Better passivation
- Simple manufacturing processes → no patterning

1. From solar cells to modules

EPFL

Challenges:
- **Optical losses** → reflection of photons at rear surface)
- **Recombination losses** → at metallic contact
- **Ohmic losses** → high series resistance at interfaces

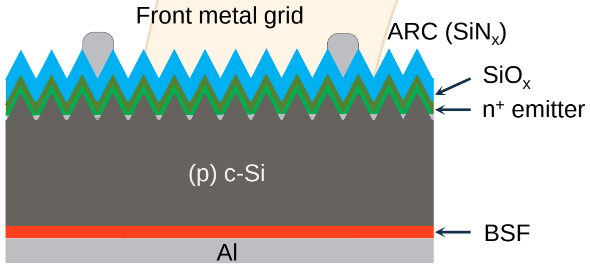
Silicon Heterojunction (SHJ)



Advantages:
- Better passivation
- ↓ Processing temperature
- ↓ Thickness, ↓ cost
- ↑ Open-circuit voltage (V_{OC})
- ↓ Temperature coefficient

Challenges:
- Need of ECA for soldering
- ↓ adhesion fingers/TCO

Aluminium Back Surface Field (Al-BSF)

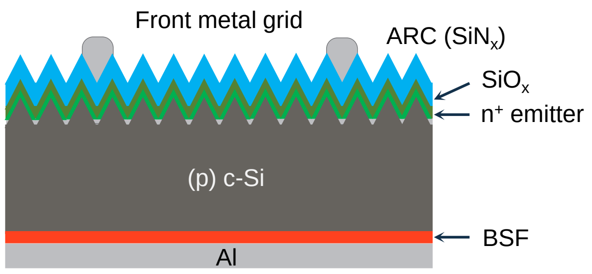


ECA: electrically conductive adhesive
TCO: transparent conductive oxide

1. From solar cells to modules

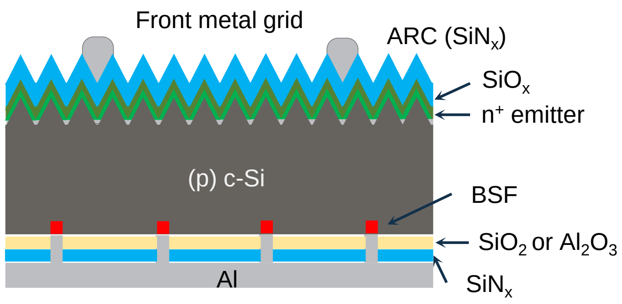
Potential for bifaciality

Aluminium Back Surface Field (Al-BSF)

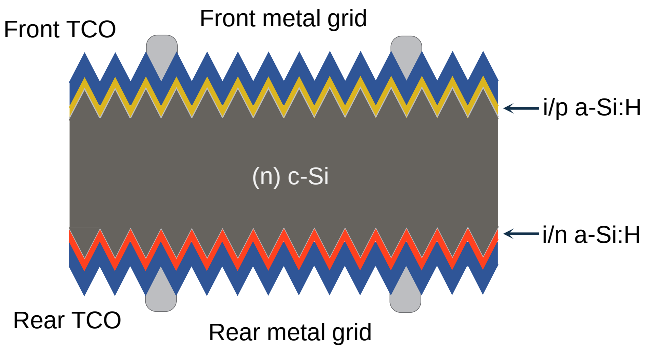


Conventional Al-BSF cells do not give option for bifaciality

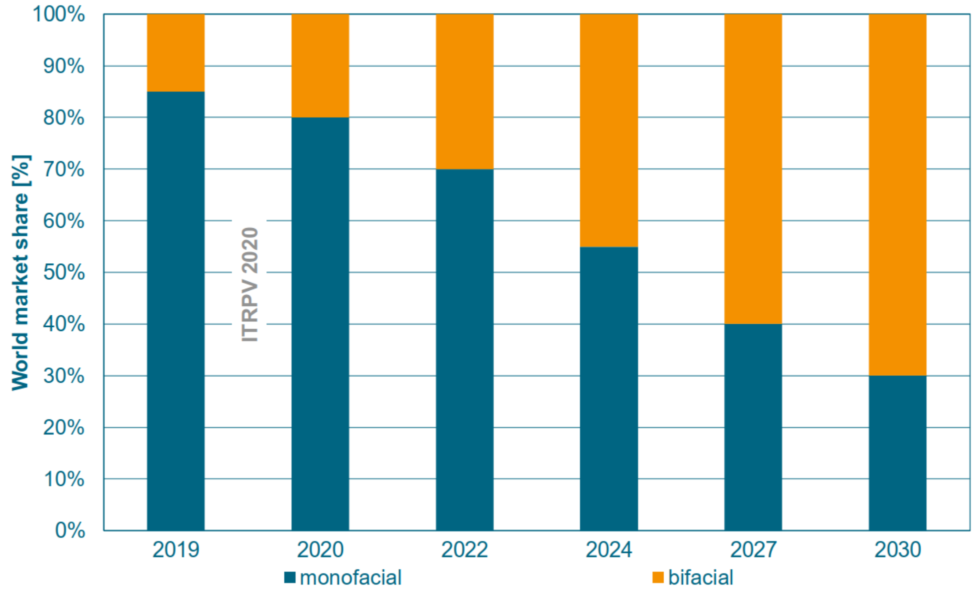
Passivated Emitter and Rear Contact (PERC)



Silicon Heterojunction (SHJ)



Bifacial cell in world market



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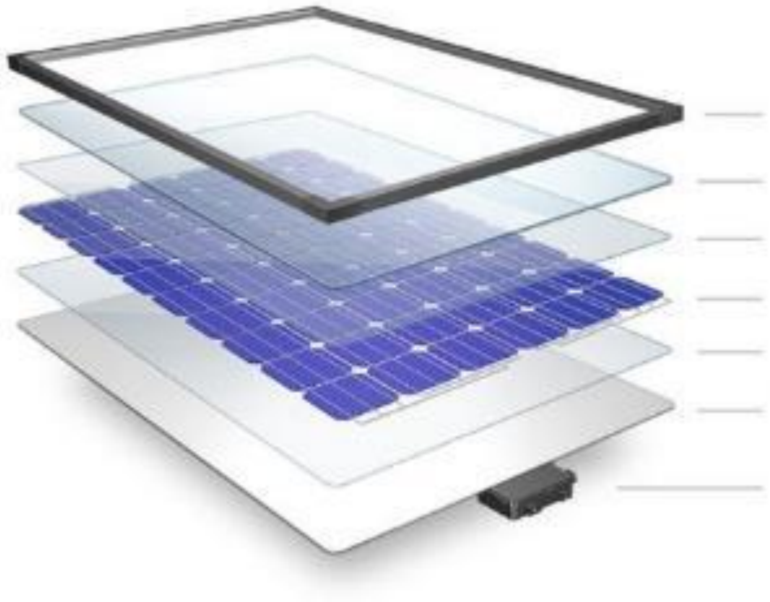
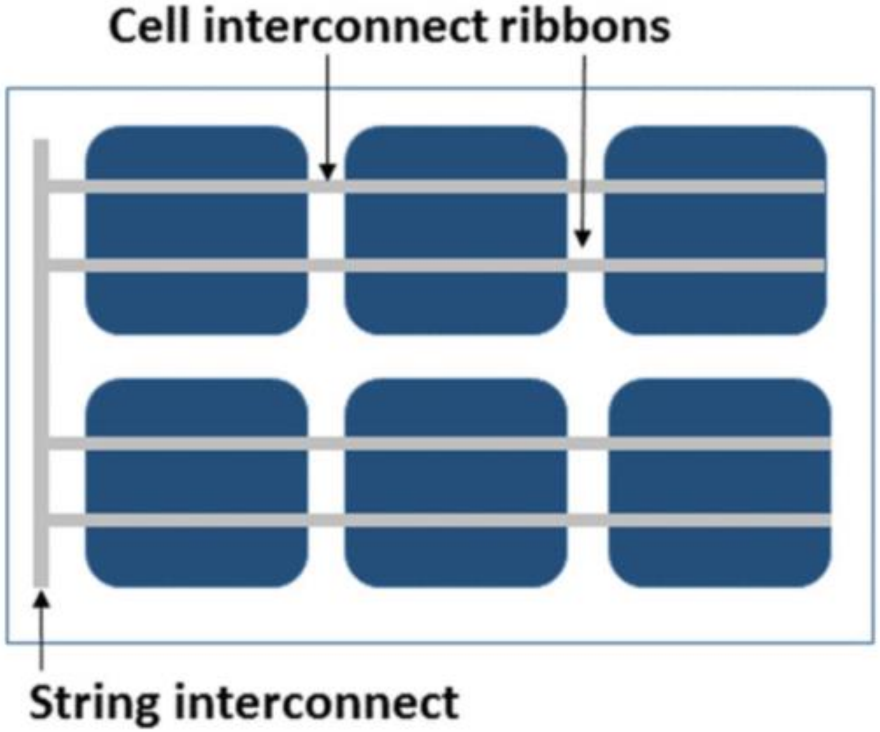
Novel solar cell concepts promote the development of bifacial technology

1. From solar cells to modules

Cell interconnections





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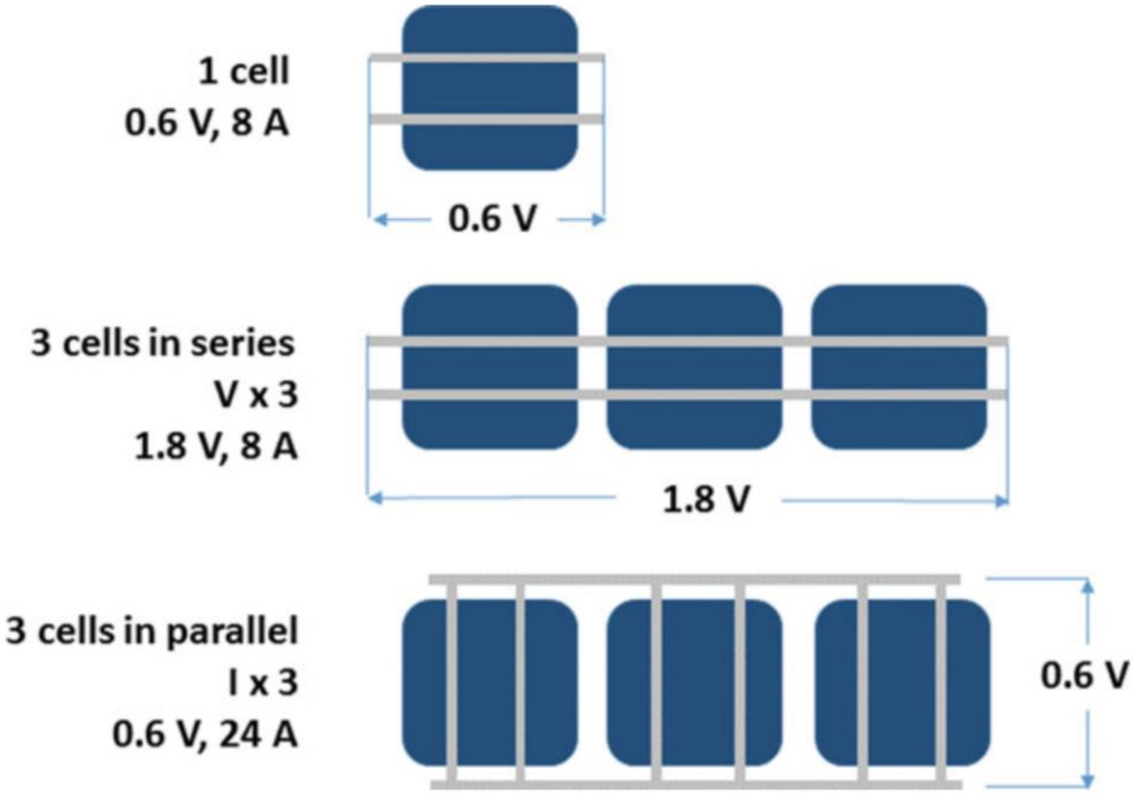
1. From solar cells to modules

Cell interconnections



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Commercial c-Si modules have 60/72 series-connected solar cells

Series connection → to get **high voltage**

- Cells must be **current-matched**

Parallel connection → currents add up

- Voltages of cells/strings need to be balanced

1. From solar cells to modules

Cell interconnections

Busbar technology

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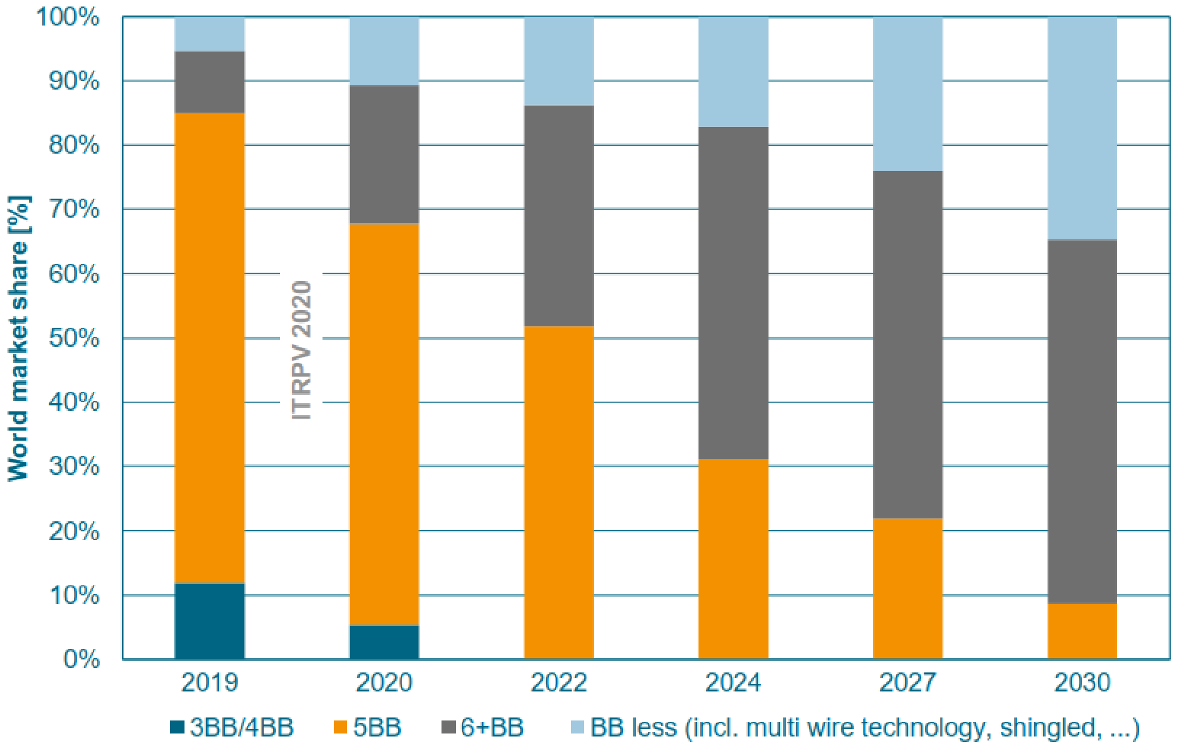

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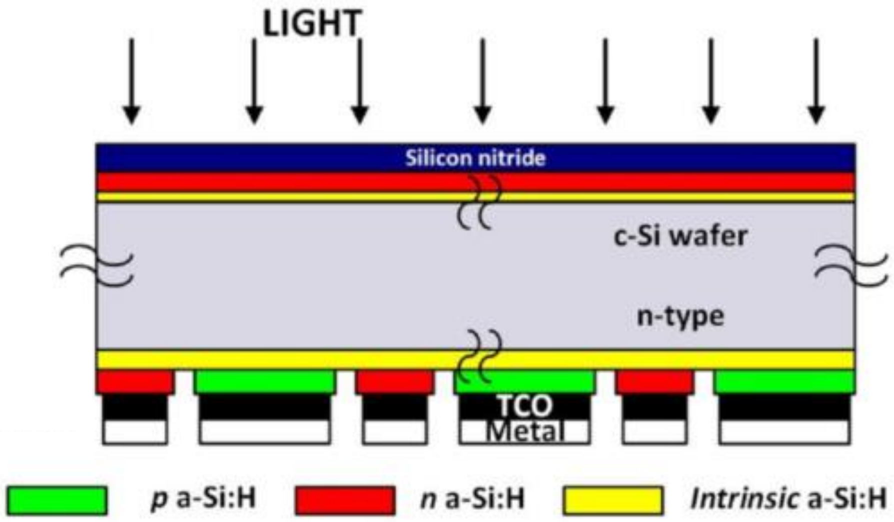
Clear trend for a higher amount of busbars or none at all

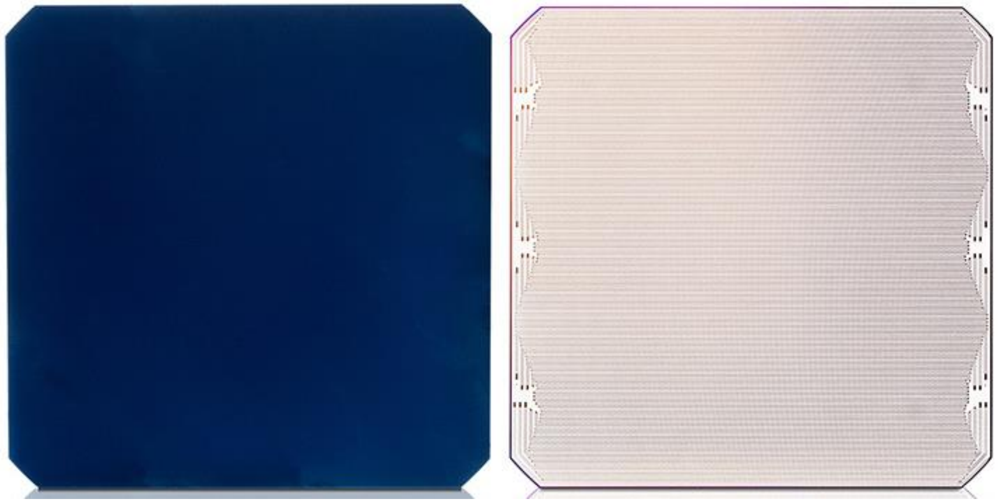
1. From solar cells to modules

Cell interconnections

Interdigitated Back Contact (IBC) solar cells –
no need of busbars



Y. Lee et al., Israel Journal of Chemistry (2015)



Advantages:
- More aesthetically appealing.
- Ideal candidate for Building Integrated PV (BIPV)

Challenges:
- Cost

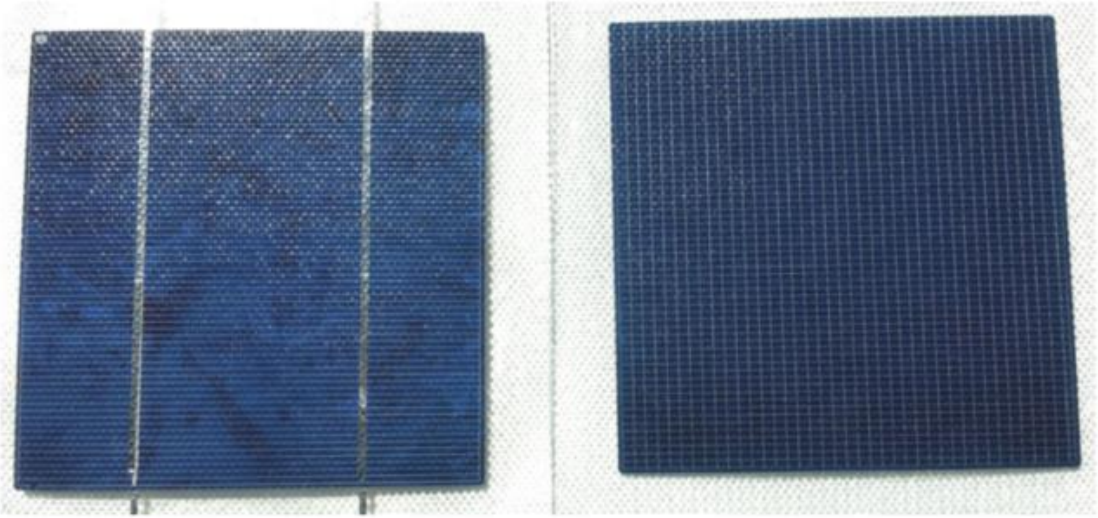
1. From solar cells to modules

Cell interconnections

Smart-wire technology (SWT)

Multi-ribbon/multi-wire technology (MWT)

- Conventional ribbons and busbars replaced by round wires with small diameter.
- Ribbons (3-6) replaced by 20+ wires.
- ↑ ribbons ⟶ ↓ current distribution ⟶ wires with lower conductance
- ↓ silver consumption
- ↓ sensitivity of cell/module to cracks/breakages ⟶ ↑ durability



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1. From solar cells to modules

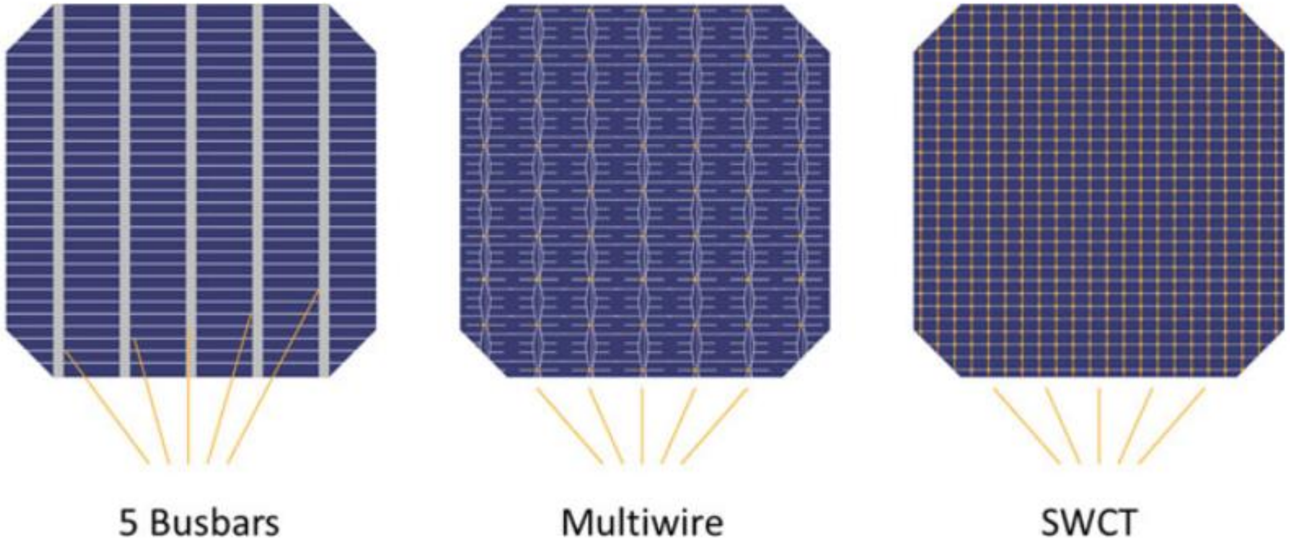
Cell interconnections

Silicon Heterojunction solar cells

Conventional soldering processes require **high temperatures** → need to find a solution for SHJ

Low temperature process → ribbons are "soldered" by using:

- **Busbar technology** → not mainstream
- **Electrically Conductive Adhesives (ECA)**
- **MWT/SWCT.**



A. Shah, Solar cells and modules (2020)

Challenges:

- Use of more silver.
- More expensive.
- Need to adapt stringers in commercial manufacturing processes.

1. From solar cells to modules

EPFL

Why don't we install bare cells in the field?

PV modules are exposed to **external stressors**:

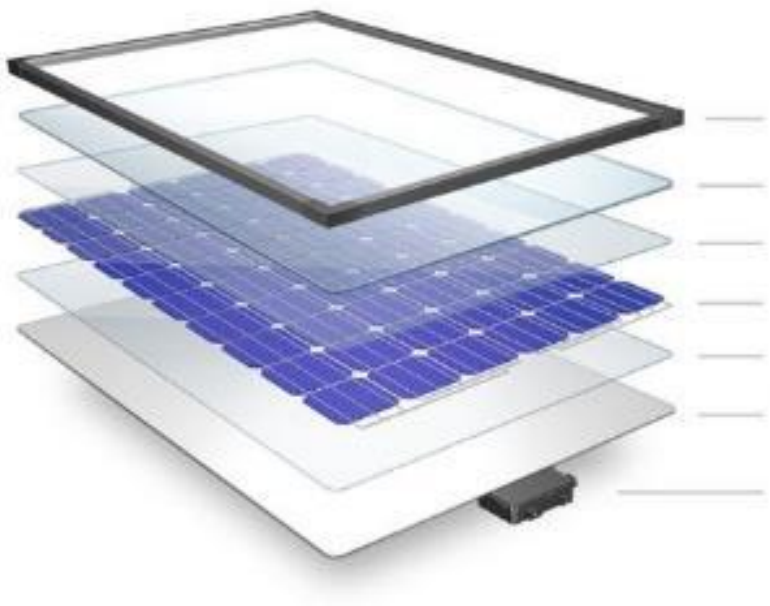
- Temperature variations due to performance and environment.
- High humidity conditions.
- Mechanical stress → rain, dust, hail..
- UV radiation

Solar cells and interconnections are **encapsulated/packaged** to:

1. **Protect electrical circuit** from weathering.
2. Provide **structural stability** and protect **mechanical integrity.**
3. **Isolate electrical circuit** from environment (e.g. protect operators from electrical shocks).

1. From solar cells to modules

Modules – Innovative concepts



Innovative module concepts target:

1. Increased module performance by reducing Cell-to-Module losses.
2. Increased energy-yield.
3. Increased reliability.

1. From solar cells to modules

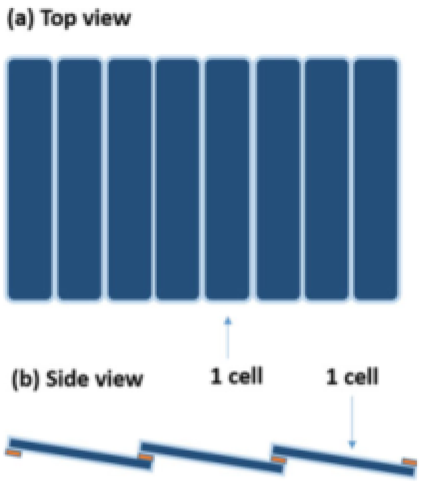
Modules – Innovative concepts

1. **Increased module performance**
2. Increased energy-yield
3. Increased reliability

Half-cell modules → ↓ cell interconnection losses

Shingled solar cells → ↓ inactive space

Light capturing ribbons → ↓ shadding losses



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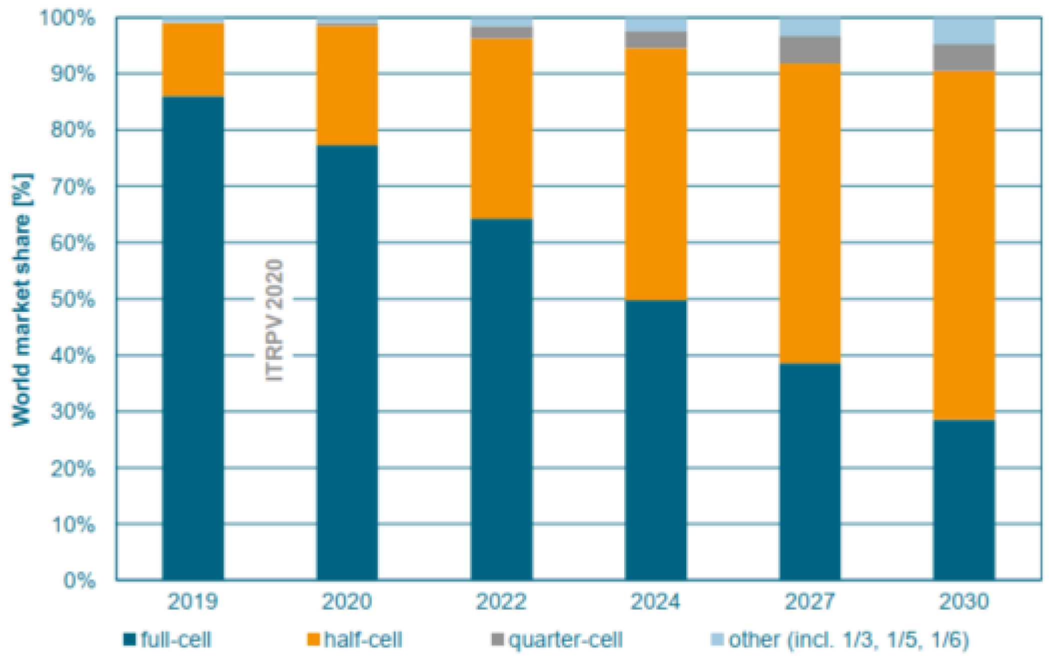
Different cell dimensions in c-Si modules



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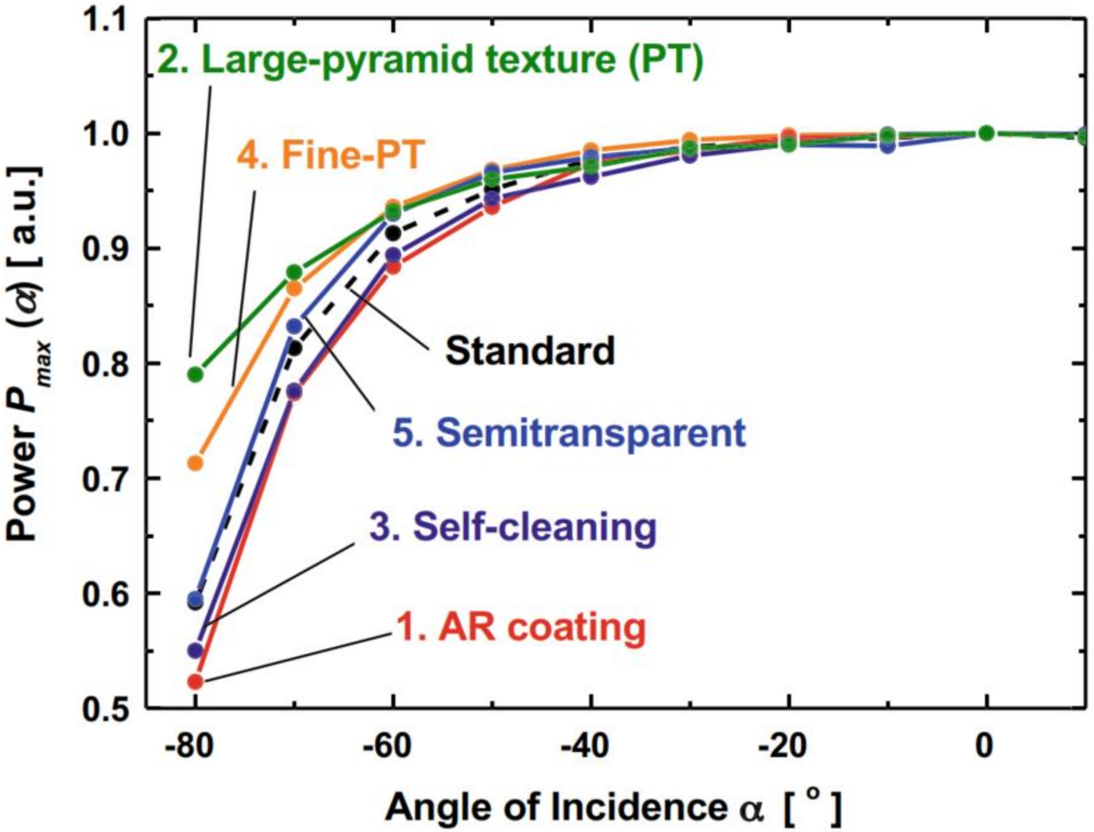
1. From solar cells to modules

Modules – Innovative concepts

1. Increased module performance
2. **Increased energy-yield**
3. Increased reliability

Anti-reflection coatings (ARC) on front surface of front glass → ↓ reflection at front glass/air interface

Textured glass → ↑ collection of light at low angles



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1. From solar cells to modules

Modules – Innovative concepts

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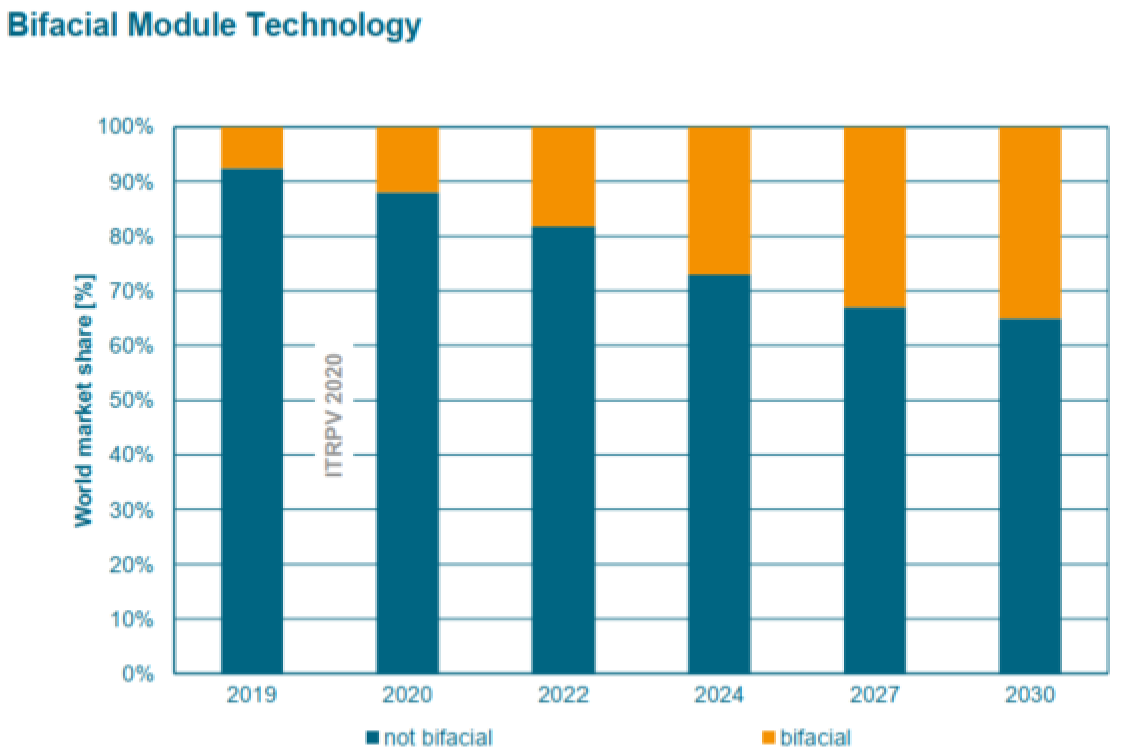
Textured glass → ↑ collection of light at low angles

Bifacial cells/modules → collection of sunlight reflected by ground



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1. From solar cells to modules

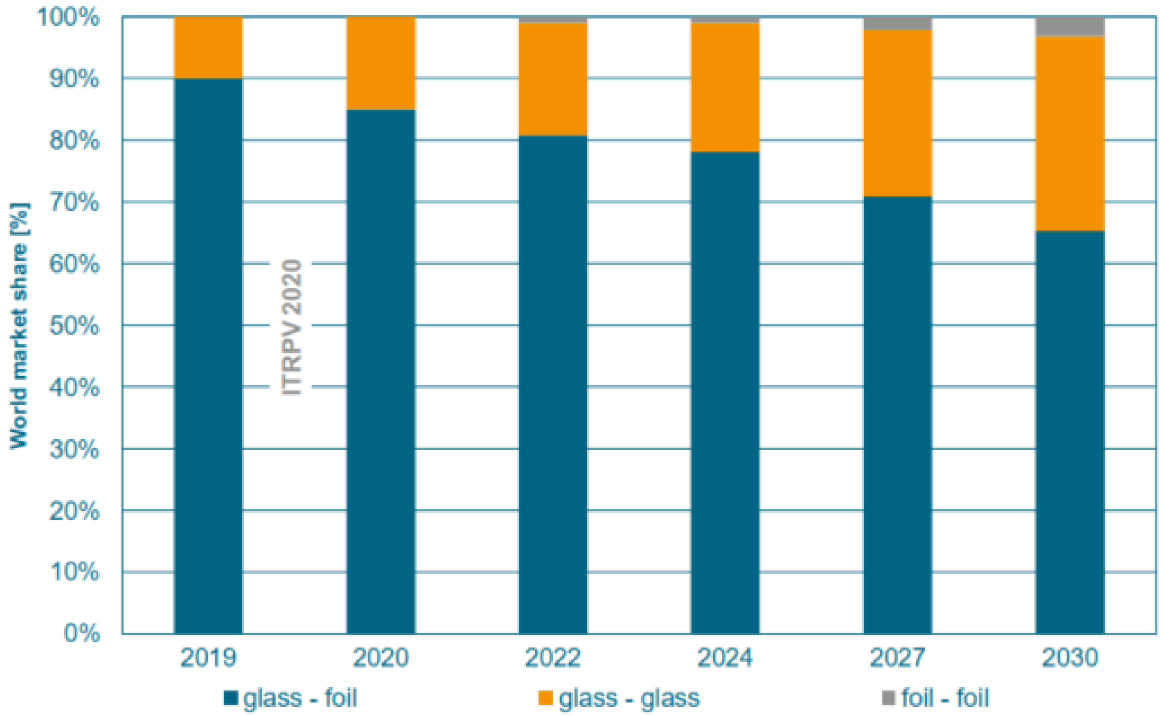
Modules – Innovative concepts

1. Increased module performance
2. Increased energy-yield
3. **Increased reliability**

Glass/glass modules → additional protection in harsh environments (snow, hail or wind loads)

SWT and MWT → minimize the impact of cracks on the performance.

Different back cover materials for modules



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