High-TR Conductive Substrate for Bifacial BC Modules

Nicolas Guillevin | TNO Solar Energy

13th workshop on BC cell and module technology, Amsterdam, 2025

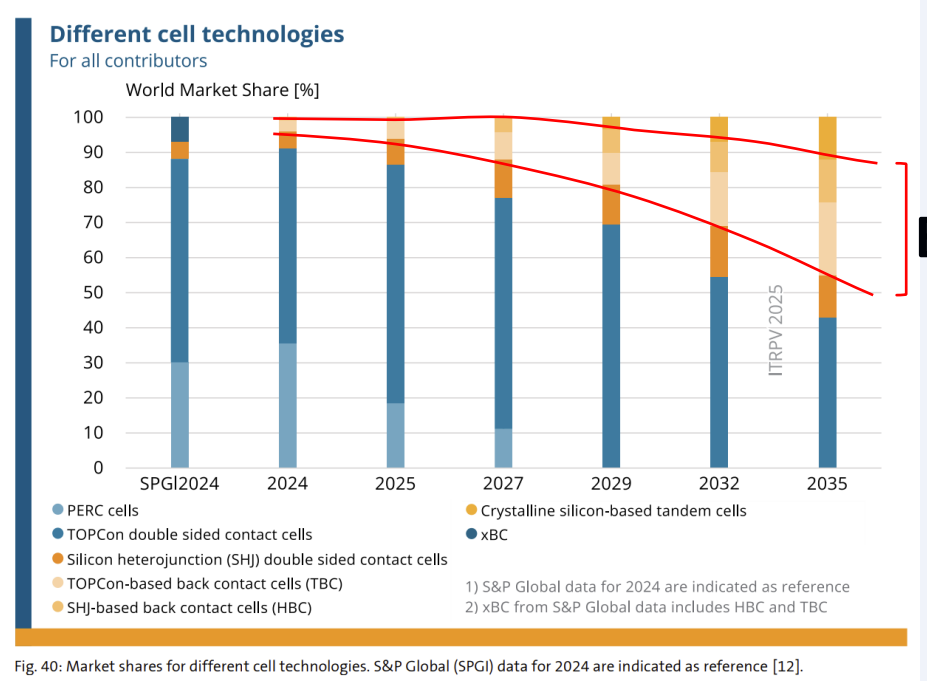
Outline

- **BC** and **Bifacial** technologies: Market predictions & current situation
- The **benefits of bifaciality** and where does it fit best
- Interconnection of BC cells by TNO:

  Technology evolution **from mono- to bi-facial** modules
- Take-aways

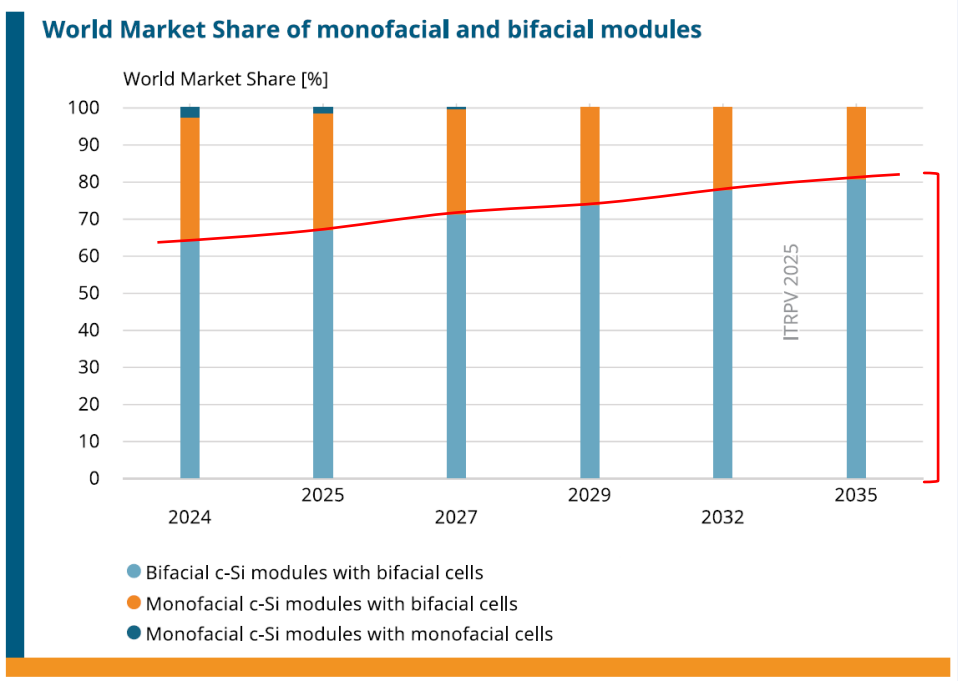
ITRPV – 16th Edition, May 2025

- BC cell concepts expected to get a **market share of up to 33% by 2035**
- Bifacial becomes the default:
  - Bifacial cells already **dominate production**
  - ≈26% are still laminated into monofacial modules
  - Bifacial module architecture will capture most utility-scale deployments by 2035.



BC

Fig. 40: Market shares for different cell technologies. S&P Global (SPGI) data for 2024 are indicated as reference [12].



Bifacial

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*BC: Back-contact - IBC: Interdigitated Back-Contact - ABC: All Back-Contact - TBC: TOPCon Back Contact - HPBC: Hybrid Passivated Back Contact
** as advertised on manufacturer website or recent press releases

BC Technology in Today's PV Module Market

Manufacturer	Product / Series	Cell Technology*	Max module Efficiency**	Mono- or Bi-facial?	Interconnection Technology
RECOM TECHNOLOGIES	Black Tiger Series	TBC	25%	Monofacial	Ribbon soldering
AIKO	NEOSTAR 3rd Gen	ABC	25%	Bifacial – 70%	Ribbon soldering – 0BB
LONGi SOLAR	Hi-MO Series (X10)	HPBC 2.0	24.8%	Bifacial – 70%	Ribbon soldering – 0BB
Sunpal	GBC Dual Glass	BC	24.5%	Bifacial – 70%	Ribbon soldering – 0BB
SPIC	Andromeda 3.0	TBC	24.2%	Bifacial – 70%	Ribbon soldering
maxeon	Maxeon 7	IBC	24.1%	Monofacial	Laser Welding
AEG	AS-M1081B-GA	HPBC	24%	Monofacial	Ribbon soldering
WAAREE One with the Sun	Tejomay Series	TBC	23.8%	Bifacial – 75%	Ribbon soldering – 0BB
SUNEVO	EVO B Series	BC	23.2%	Monofacial	Full Back Welding

- **50%** of the top high-efficiency PV modules on the market use **back-contact cell** technology
- **All soldered/welded** interconnections with alignment tolerances becoming tighter (0-Busbar)
- **Over 50%** of manufacturers offer a **bifacial** version of their back-contact flagship modules

Why Bifacial?

• **Higher Energy Yield**	5–30% more energy output.
• **Better Performance in Diffuse Light**	Improved efficiency in cloudy conditions.
• **Lower Levelized Cost of Energy**	Reduced lifetime system cost.
• **Enhanced Durability (glass/glass)**	Stronger, longer lifespan, lower degradation
• **Optimized for Advanced Mounting & Applications**	Elevated structures, high-albedo surfaces, floating-PV, agri-PV.
• **Design Flexibility & Aesthetics**	Suitable for BIPV.

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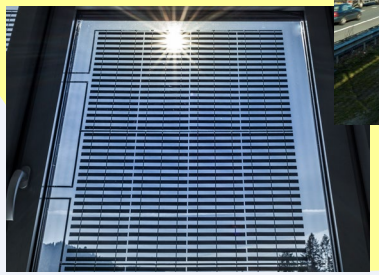
Bifacial PV in Natural and Built Environment

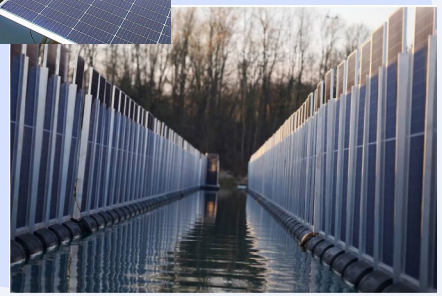
Utility-scale solar farms

Building/Infra



Carports & Parking

Floating-PV



Back-contact + Bifacial
Performance & Aesthetics

Agri-PV

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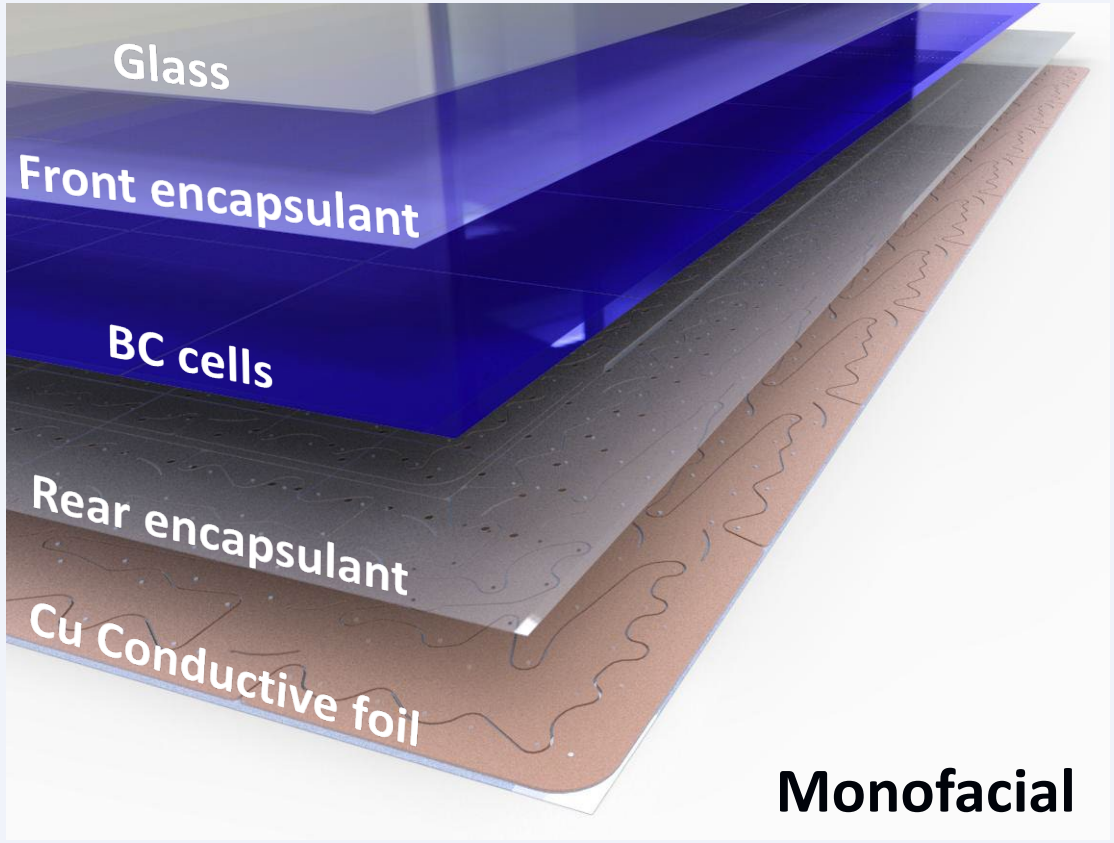
TNO's Conductive Foil Interconnection Technology



- Suitable for **any BC cell** technology
- Design for **low interconnection CtM losses**
- Ultimate (electrical) design **flexibility** (PCB-like)
- **Low-stress** assembly (pick & place)
- **1-step** interconnection & encapsulation at **low-T** (<150°C)
- Suitable for **larger** and **thinner** wafers
- Allows **high packing density**
- High production **speed and yield**
- Proven on **GW scale**

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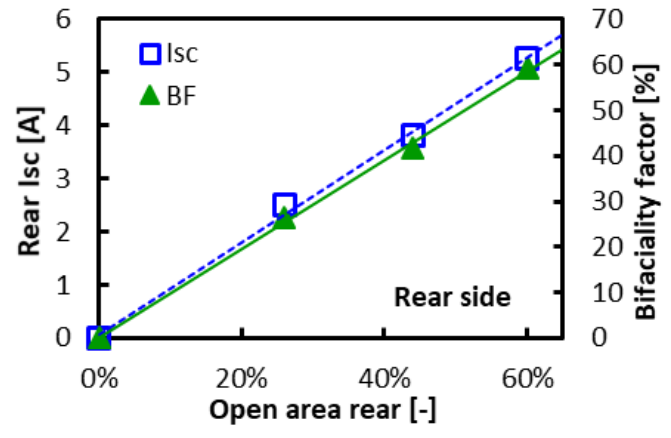
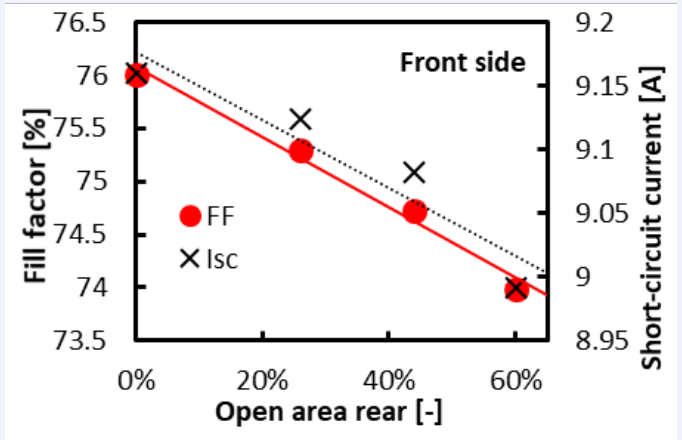
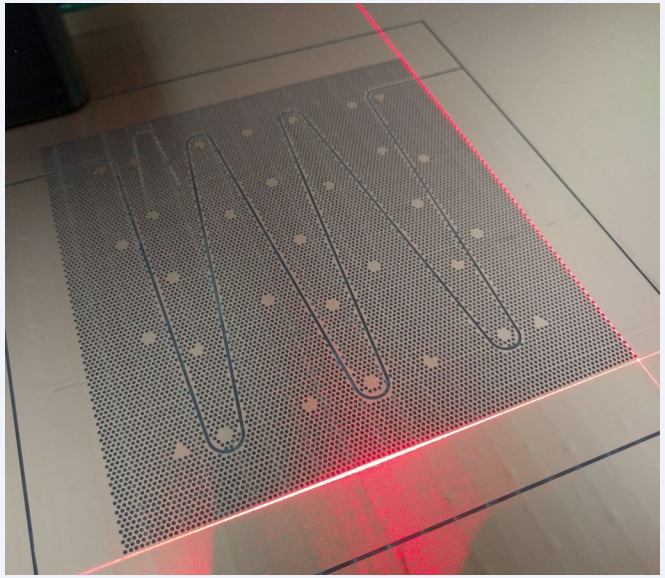
From Monofacial to Bifacial Conductive Foil

- Early developments removing (perforating) Cu layer from foil
- Bi-faciality level from **25% to 60%** tested on single-cell laminates







- Module performance **trade-off**:
  - **bifaciality** ➔ amount of Cu removed
  - **resistive losses** ➔ line conductivity of interconnection tracks
- **Subtractive** manufacturing method ➔ Cu material waste

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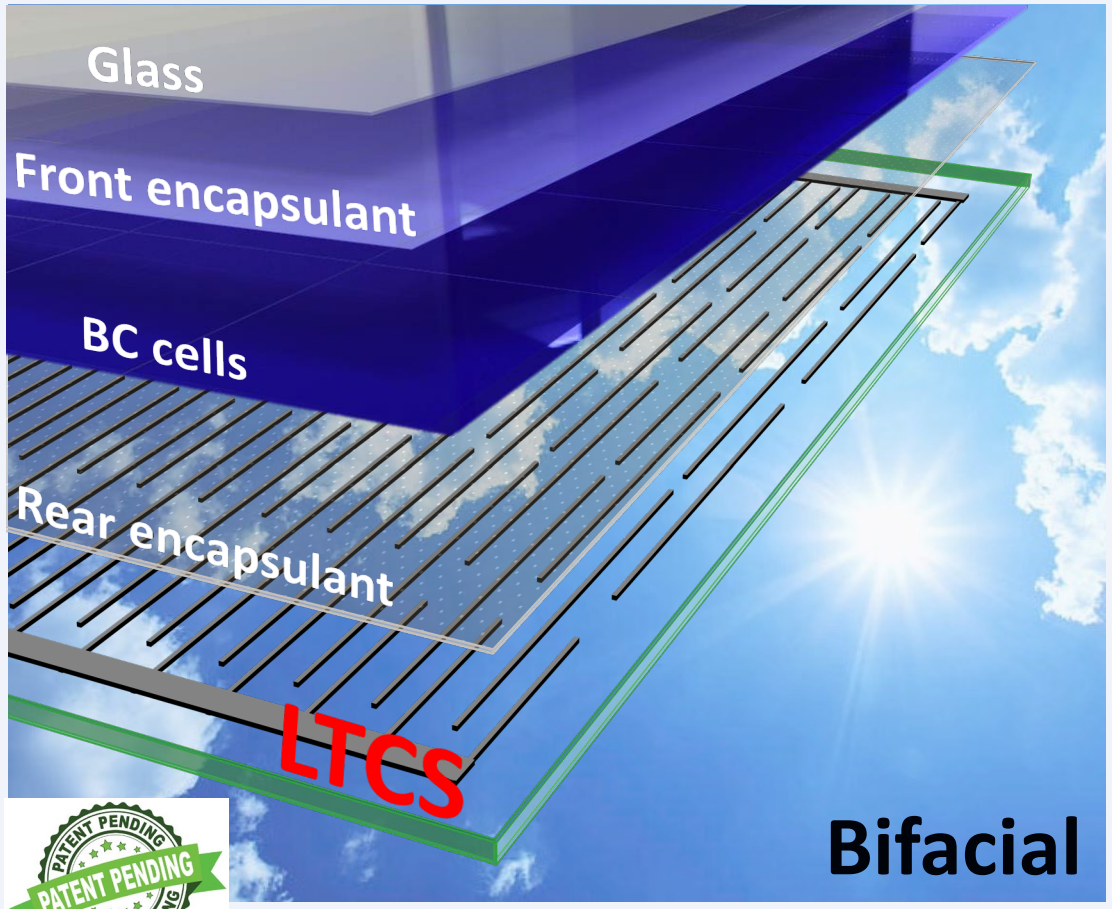
TNO's Bifacial BC Interconnection Technology



- Light transmitting conductive substrate (**LTCS**)

  ➔ Conductive tracks **integrated to the rear-glass**
- **Same assembly process and benefits** as the conductive foil interconnection technology

+ added features:

➔ **High Bifaciality**

➔ **Additive** manufacturing

➔ Track aspect ratio adjustable to
- **minimize R_{series}**
- **maximize bifaciality**

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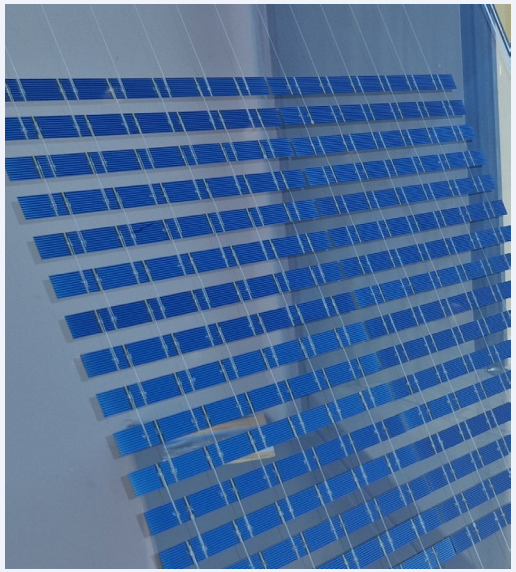
LTCS Firstly Developed For BiPV



- Design **flexibility** and manufacturability demonstrated for **PV windows**
- **Ultra-narrow** Ag interconnection tracks integrated to the rear-glass
- Strip-shaped IBC cells at 60% packing density deliver **100 Wp/m²**
- Maximum bifaciality for up to **25% energy boost** from Venetian blinds' reflection (placed behind the PV panel)

De Telegraaf NIEUWS SPORT ENTERTAINMENT FINANCIEEL VROUW LIFESTYLE WAT U ZEGT

Lees voor

TNO maakt dubbelzijdig zonneraam: opwek stroom aan binnen- en buitenkant woning

Door THEO BESTEMAN
14 nov. 2024 in FINANCIEEL

AMSTERDAM - Onderzoekers hebben een raam ontwikkeld dat stroom opwekt als een zonnecel en tegelijkertijd de warmte en lichtinval regelt. Het kent dubbelzijdige zonnecellen en wekt aan binnen- en buitenkant stroom op.

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Het ontwikkelde raam van de onderzoeksgroep onder leiding van TNO.

Outdoor Performance Analysis of Semitransparent Photovoltaic Windows with Bifacial Cells and Integrated Blinds - Villa - 2024 - Solar RRL
https://onlinelibrary.wiley.com/doi/full/10.1002/solr.202400515

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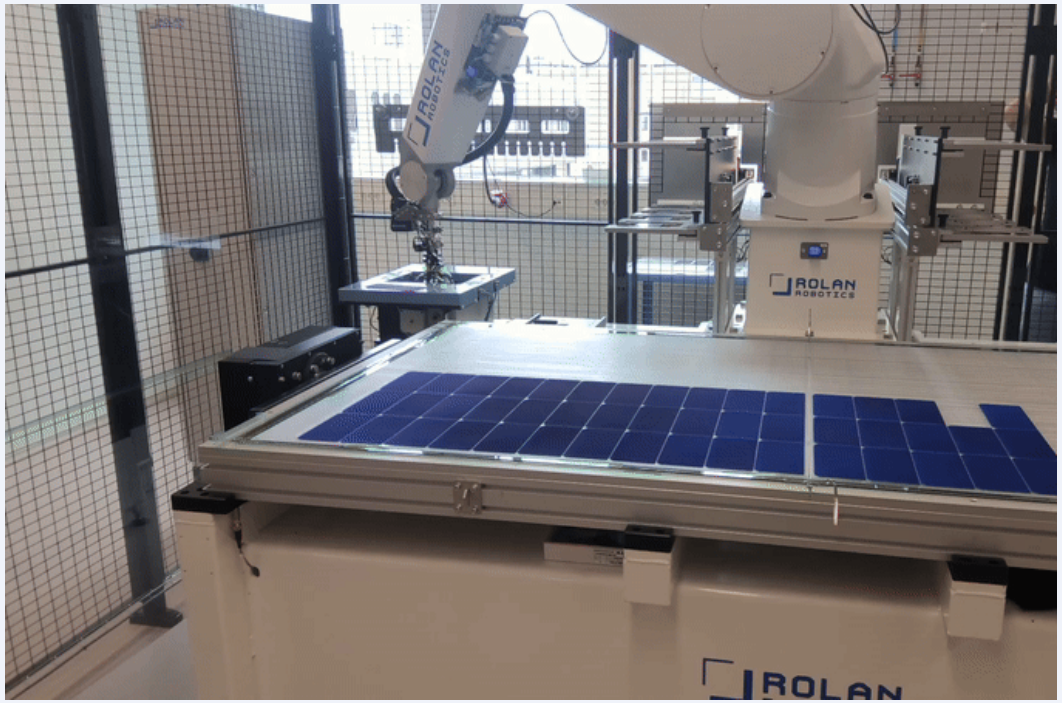
LTCS Applied To Standard Panel Format

- Full-size module prototypes assembled on TNO's pilot line
- 132 ½-cut IBC Zebra cells (M6 size)



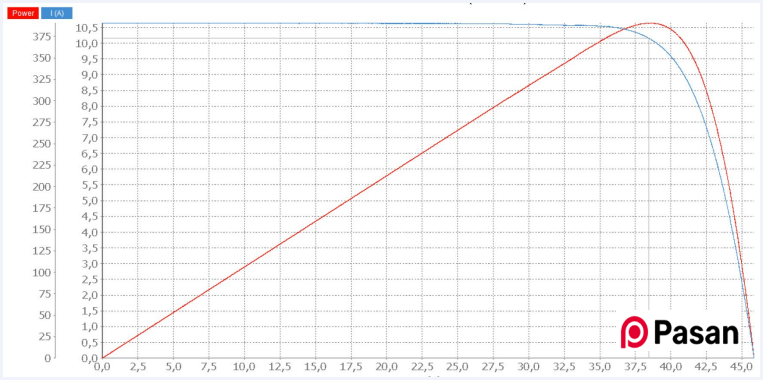
TNO's pick and place robot assembling a bifacial module

Front-side (left) and rear-side (right) of TNO's bifacial BC module

LTCS Applied To Standard Panel Format

- **High performance prototype with low Cell-to-Module losses**

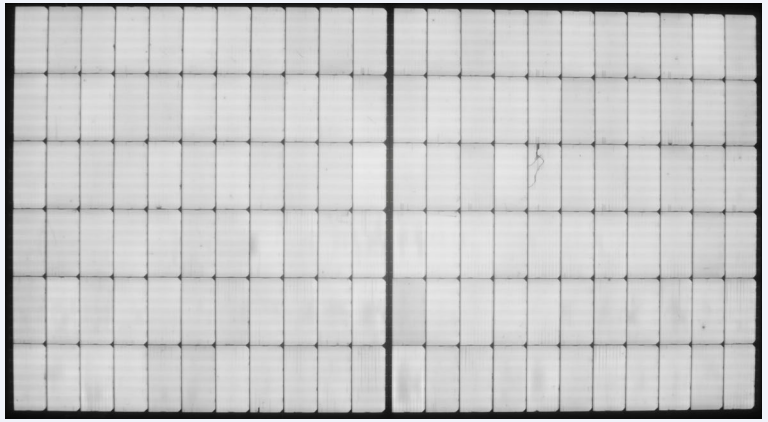
	Pm[W]	Isc[A]	Imp[A]	Voc[V]	Vmp[V]	FF[%]
Front side I/V	384.5	10.6	10.1	45.8	38.2	78.8
½-cut cells av.	3.1	5.7	5.4	0.687	0.576	79.8
CtM losses (%rel)	6.10%	6.67%		0.40%		1.2 %



I/V curve measured by PASAN flash tester

- **High bifaciality**

	Pm[W]	Isc[A]	Imp[A]	Voc[V]	Vmp[V]	FF[%]
Front side I/V	384.5	10.6	10.1	45.8	38.2	78.8
Rear side I/V	311.7	8.6	8.2	45.5	38.2	80.0
Bifaciality	81%	80%				

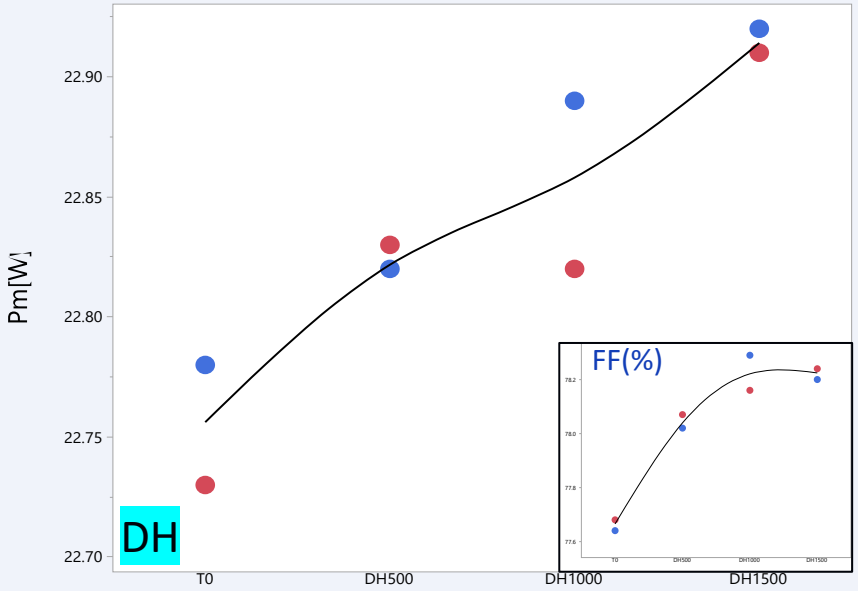

Electroluminescence measurement

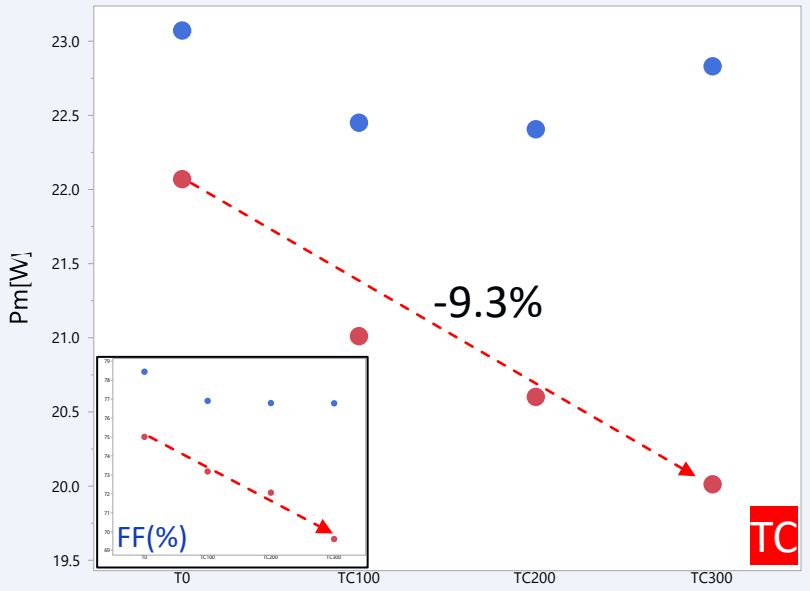
LTCS – Reliability

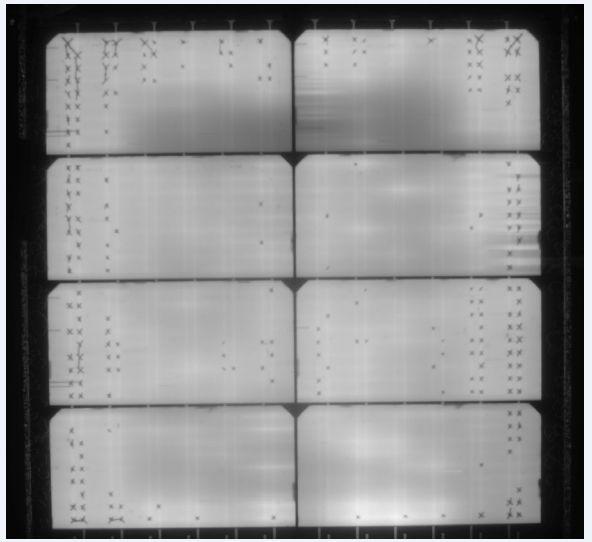
- Damp Heat (DH) and Thermal Cycling (TC) performed on mini modules (x8 ½-cut IBC cells)
- **DH:** 0.6% power increase after 1500 hours (FF related)
- **TC:** 300-cycle results indicate need for material and process optimization:

  <1% power loss for Module 1

  >9% power loss for Module 2 – Micro-cracks at interconnection points leads to FF loss







Electroluminescence measurement

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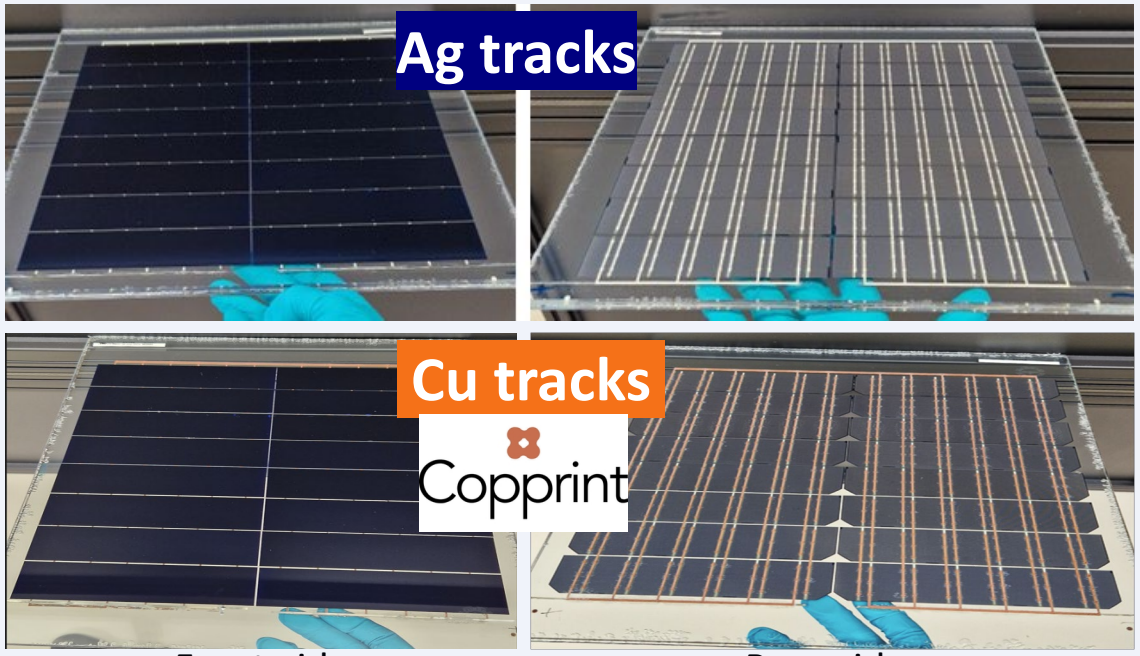
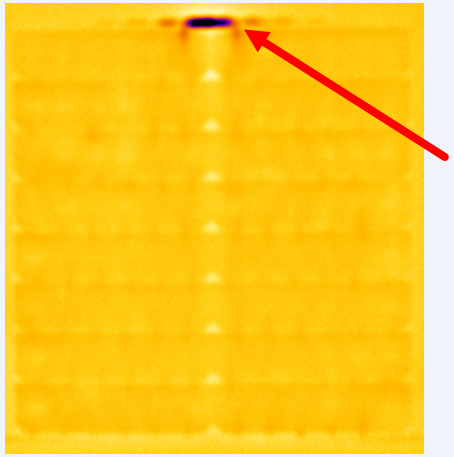
LTCS – Conductive Materials

Test modules (x16 ¼-cut Zebra IBC cells)



Front-side Rear-side

Best performing bi-facial modules		Pmax (W)	Isc (A)	Voc (V)	FF (%)
Ag tracks	Front side I/V	23.45	2.68	11.05	79.1
Cu tracks	Front side I/V	20.42	2.53	10.88	74.3



DLIT on "Cu tracks" module

High resistance in the Cu bussing explains the lower FF of the Cu track module

- From **Ag to Cu** tracks for cost reduction
- **Promising** first results highlight importance of **e-design optimization**

Take-Aways

- **BC and Bifacial** technologies expected to **lead the PV market** soon
- **Next Gen interconnection technology developed by TNO for Bifacial BC cells**
  - From Cu Foil to **Light Transmitting Conductive Substrate (LTCS)**
  - High module p**erformance** and **bifaciality (>80%)**
  - **Low stress** and **low-T** manufacturing
  - Design **Flexibility** (ideal for customisation of **IPV products**)

    ➔ Great **alternative to ribbons soldering**/welding
- **Next Steps**:
  - Improve **reliability**
  - Alternative **substrates and conductive materials**

Acknowledgments

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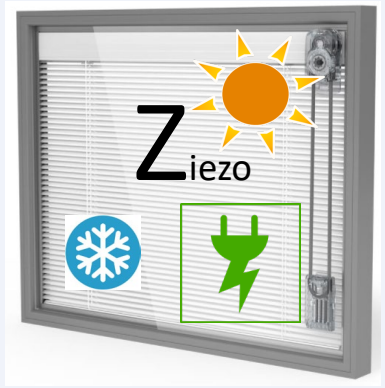

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