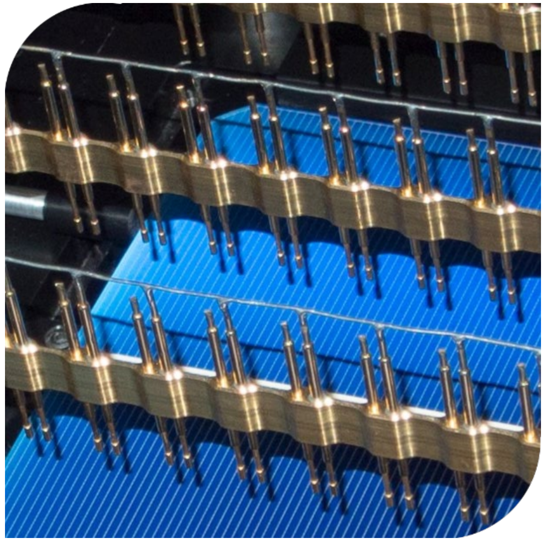



Gapless Module Layout for xBC Solar Cells

Daniel Tune, Andreas Halm, Karl Wienands, Tudor Timofte, Tobias Messmer

ISC research for a sunny future

State-of-the-art PV module

Wafer-based PV modules feature a high fraction of inactive module area

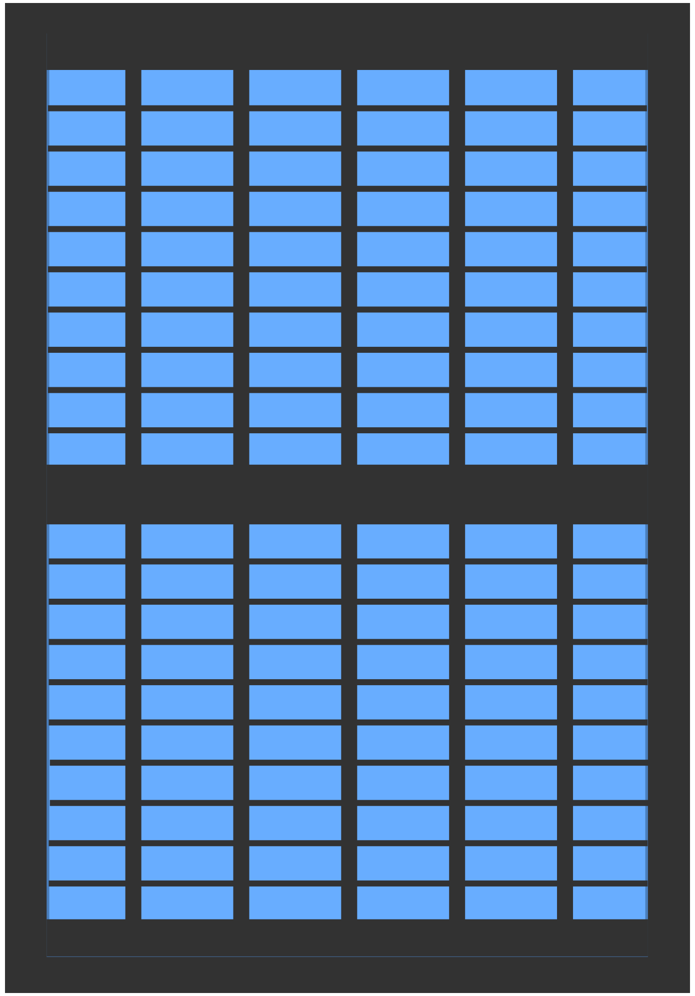
Example: **M10 module** 108 half cells

typical length: 1762 mm

typical width: 1134 mm

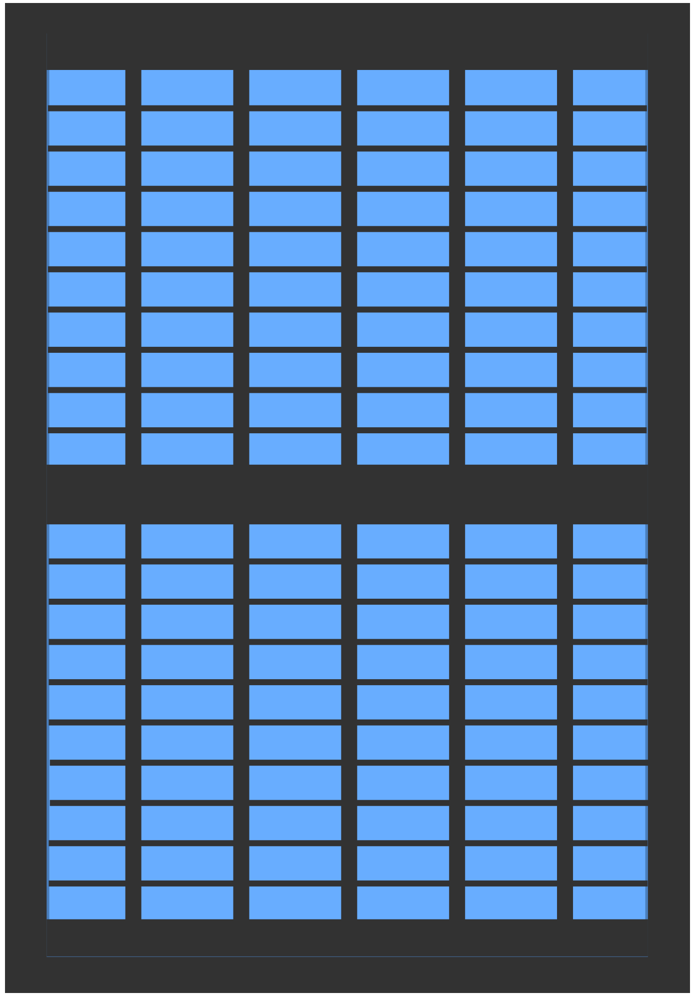
» 8.6 % inactive module area !!

See e.g.: https://www.luxor.solar/files/luxor/download/datasheets/LX_EL_N-Type_NR_BW_M108_420-440W_182_DE.pdf



State-of-the-art PV module

Wafer-based PV modules feature a high fraction of **inactive module area**



Example: **M10 module** 108 half cells

typical length: 1762 mm

typical width: 1134 mm

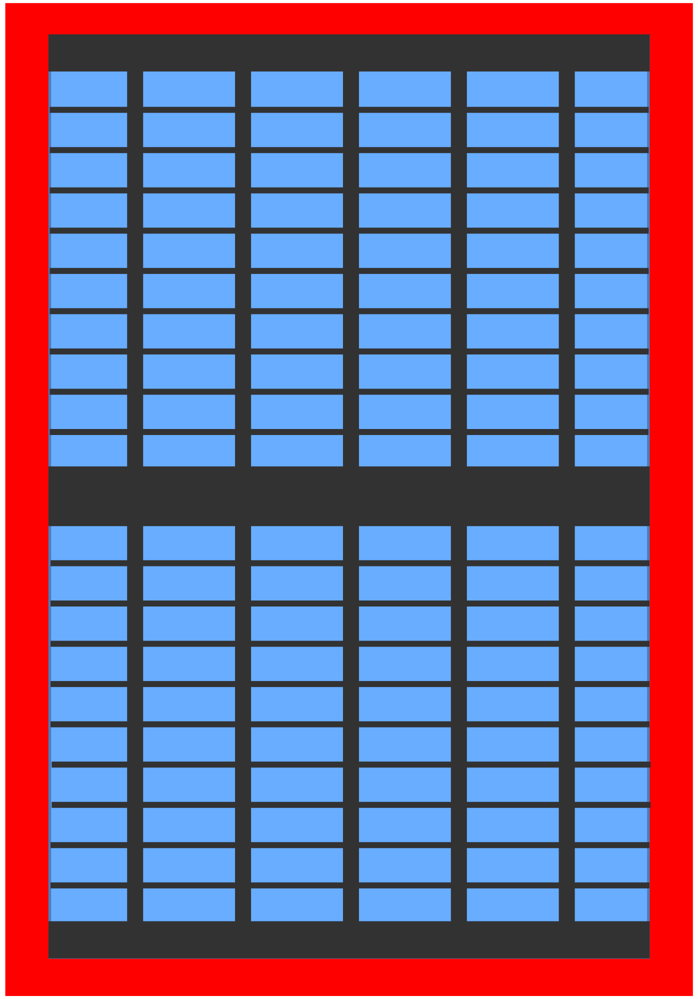
» 8.5 % inactive module area !!

» high potential to increase module efficiency

See e.g.: https://www.luxor.solar/files/luxor/download/datasheets/LX_EL_N-Type_NR_BW_M108_420-440W_182_DE.pdf

Breakdown inactive module area

Frame and safety margin (1500 V) **4.7 %**



IEC 61730-1:2023

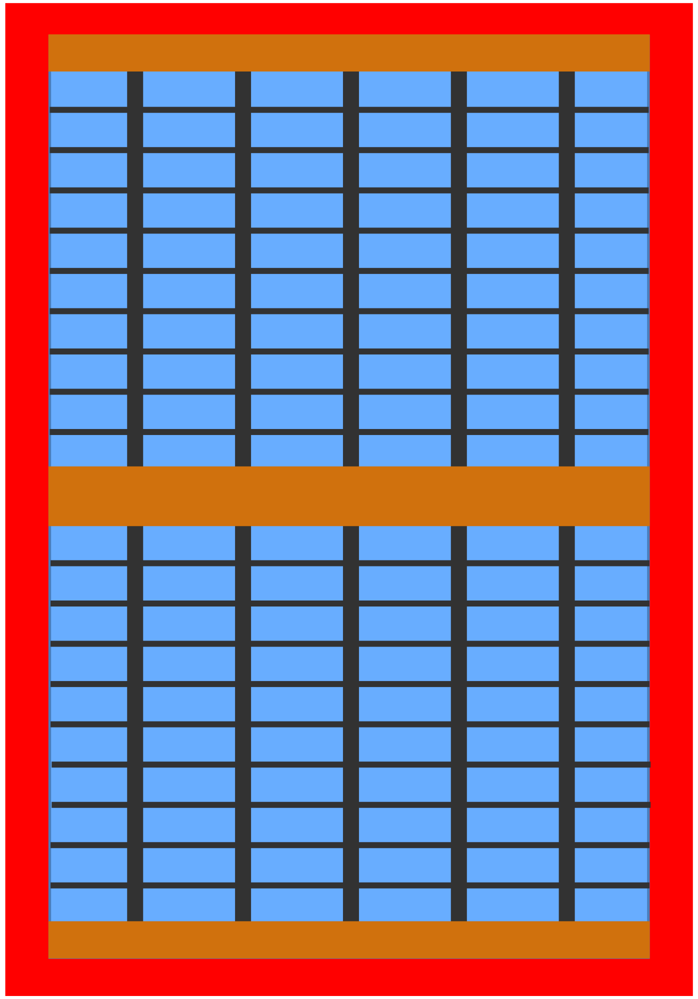
- Allows for the use of "cemented joints" (very good edge seals)
- Change from "creepage distance" along an insulator surface to "distance through insulator (DTI)" approach
- 12.4 mm cell/bussing to glass edge reduced to minimum

M10 module, 108 half cells, length: 1762 mm, width: 1134 mm

Breakdown inactive module area

Frame and safety margin (1500 V) **4.7 %**

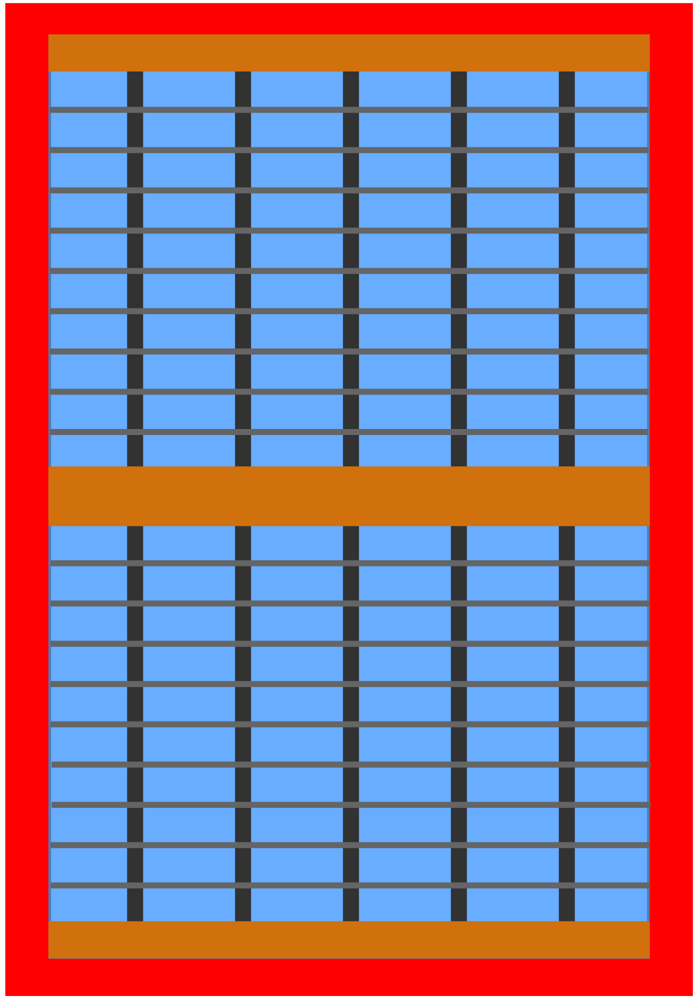
Top bussing
Butterfly gap (j-boxes) **2.8 %**
Bottom bussing



M10 module, 108 half cells, length: 1762 mm, width: 1134 mm

Breakdown inactive module area

Frame and safety margin (1500 V)	4.7 %
Top bussing Butterfly gap (j-boxes) Bottom bussing	2.8 %
Cell gaps	0.9 %



M10 module, 108 half cells, length: 1762 mm, width: 1134 mm

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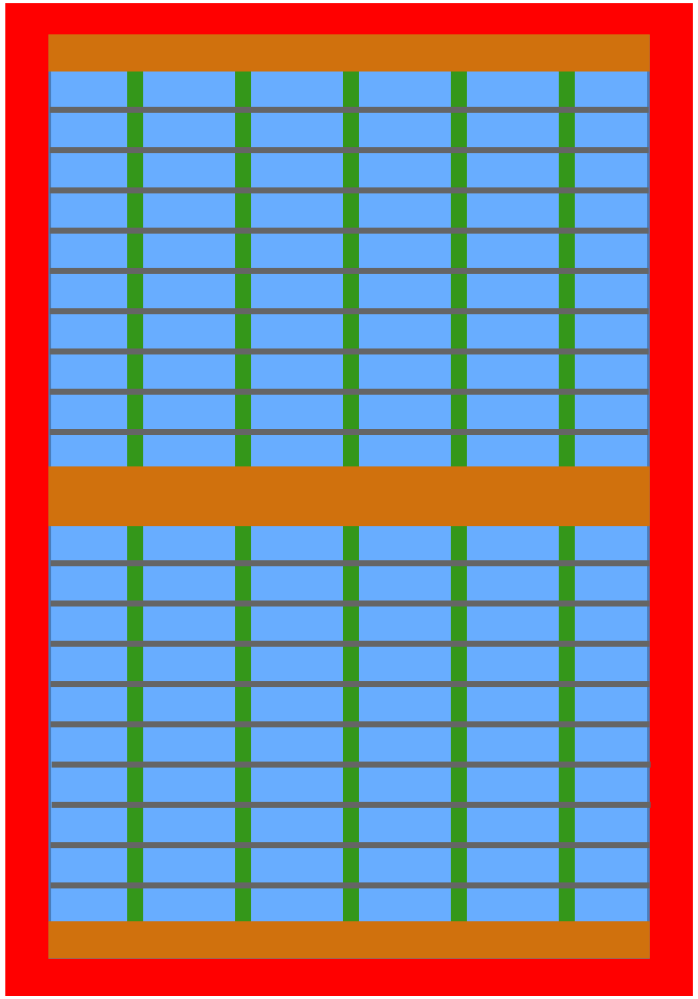


M10 module, 108 half cells, length: 1762 mm, width: 1134 mm

Potential efficiency increase by area reduction

Frame and safety margin (1500 V) 4.7 %

Top bussing **Butterfly gap (j-boxes)** **Bottom bussing**	**2.8 %**	**potential for area reduction:**
Cell gaps	**0.9 %**	**4.5 %**
String gaps	**0.8 %**	

M10 module, 108 half cells, length: 1762 mm, width: 1134 mm

Potential efficiency increase by area reduction

Frame and safety margin (1500 V) 4.7 %

~~Top bussing~~
~~Butterfly gap (j-boxes) 2.1 %~~
~~Bottom bussing~~

~~Cell gaps 0.9 %~~

~~String gaps 0.9 %~~

potential for area reduction:

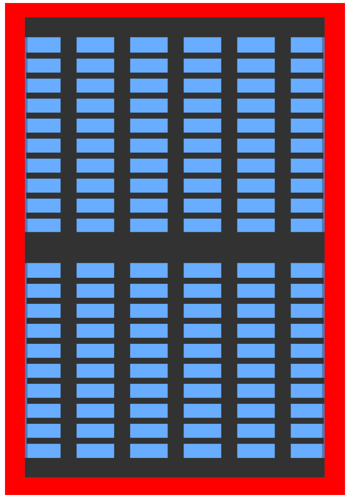
4.5 %

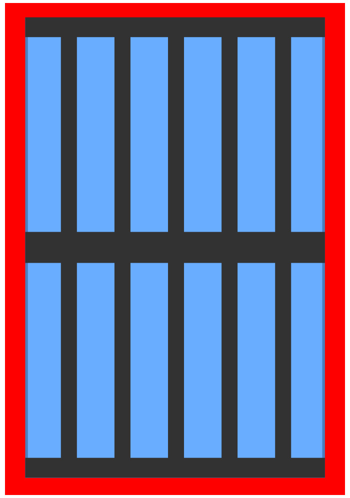
Theoretical efficiency increase for unchanged module power: 4.7 % rel.*

M10 module, 108 half cells, length: 1762 mm, width: 1134 mm

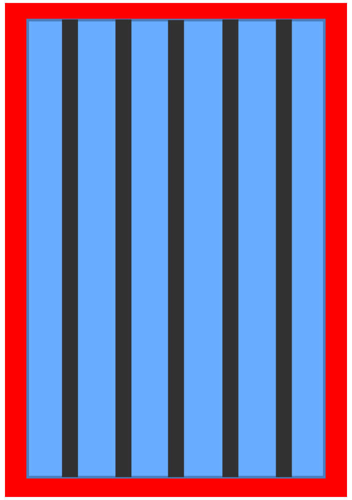
*valid for black backsheet or bifacial modules

Route to efficiency increase by area reduction



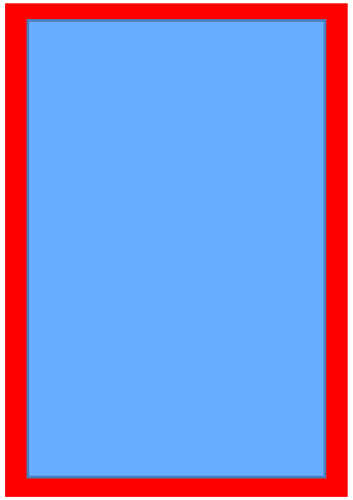


gapless stringing



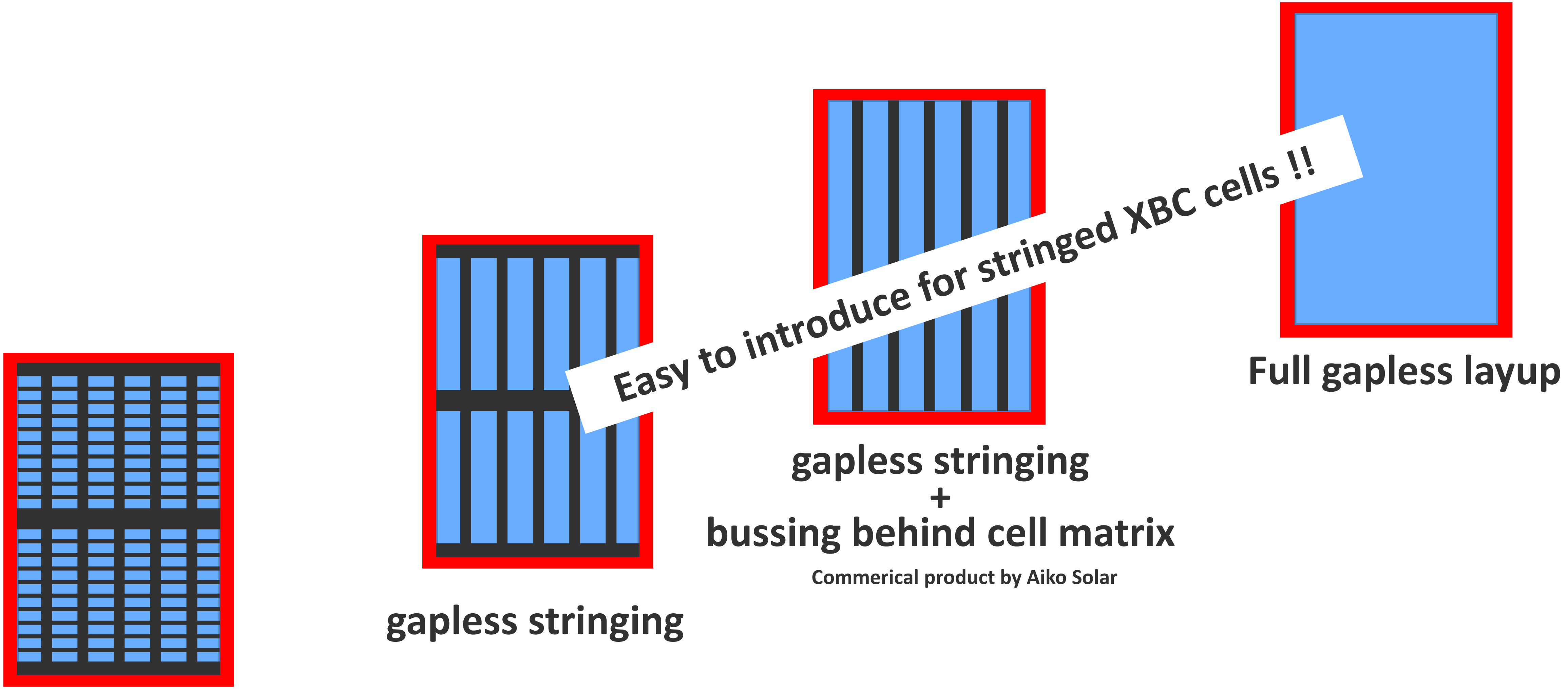
gapless stringing
+
bussing behind cell matrix

Commerical product by Aiko Solar



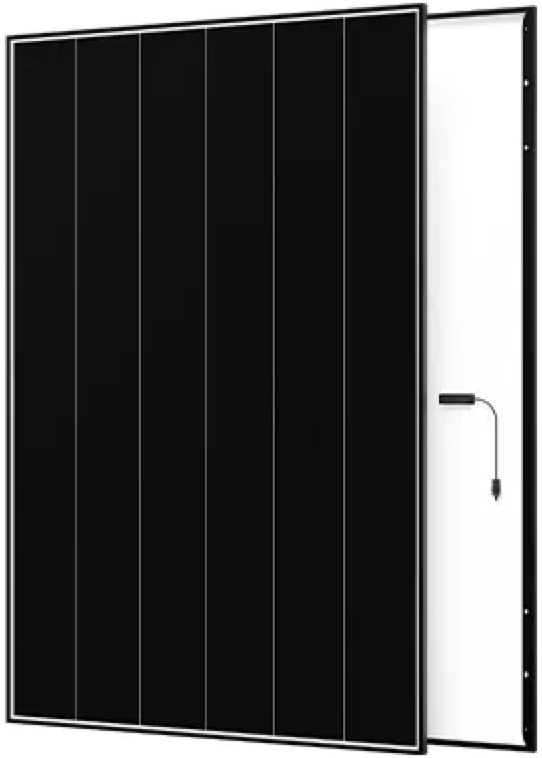
Full gapless layup

Route to efficiency increase by area reduction



Technical solutions enabled by back contact cell stringing

Bussing behind cell matrix



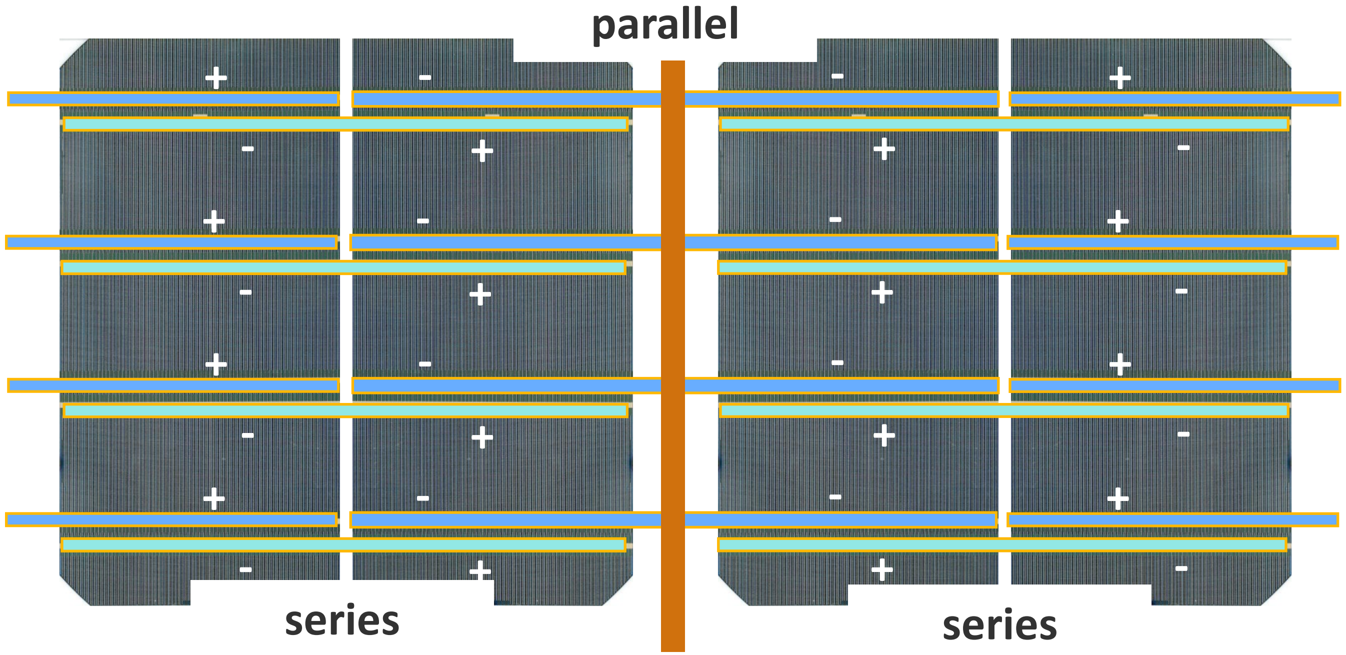
Commercial product available from Aiko Solar:

Modul Neostar ABC Gen 3

» already in mass production !!

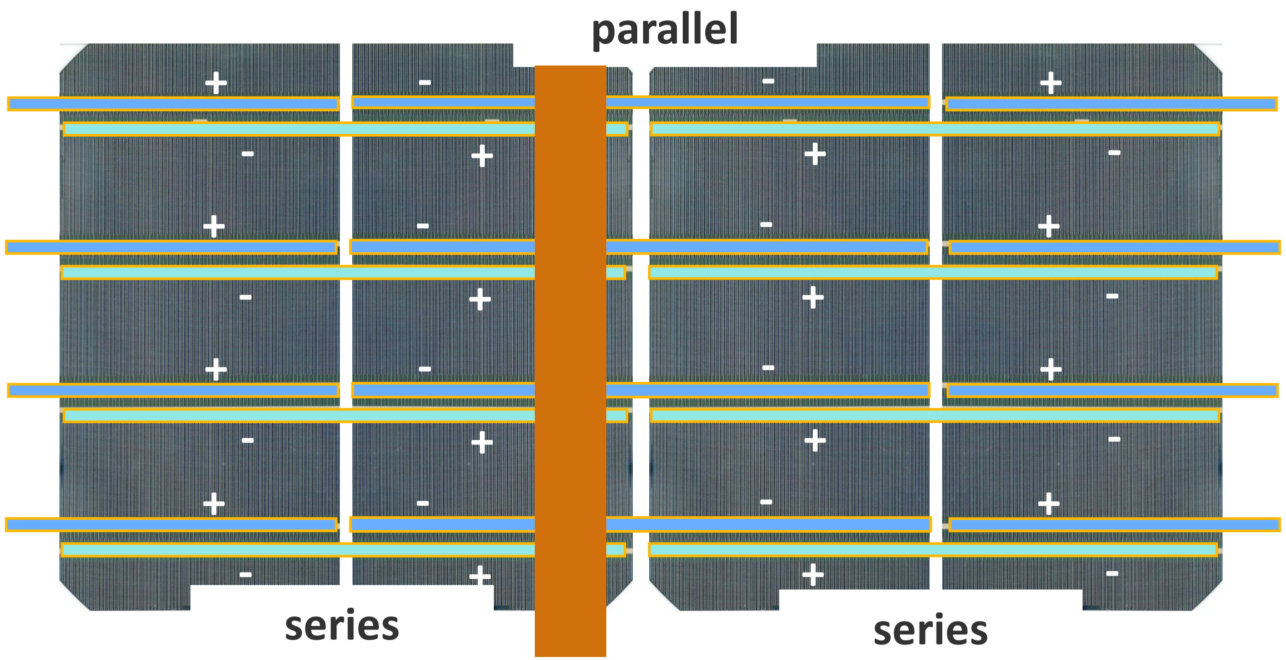
Avoiding butterfly gap by rear-side bussing

Standard butterfly



Avoiding butterfly gap by rear-side bussing

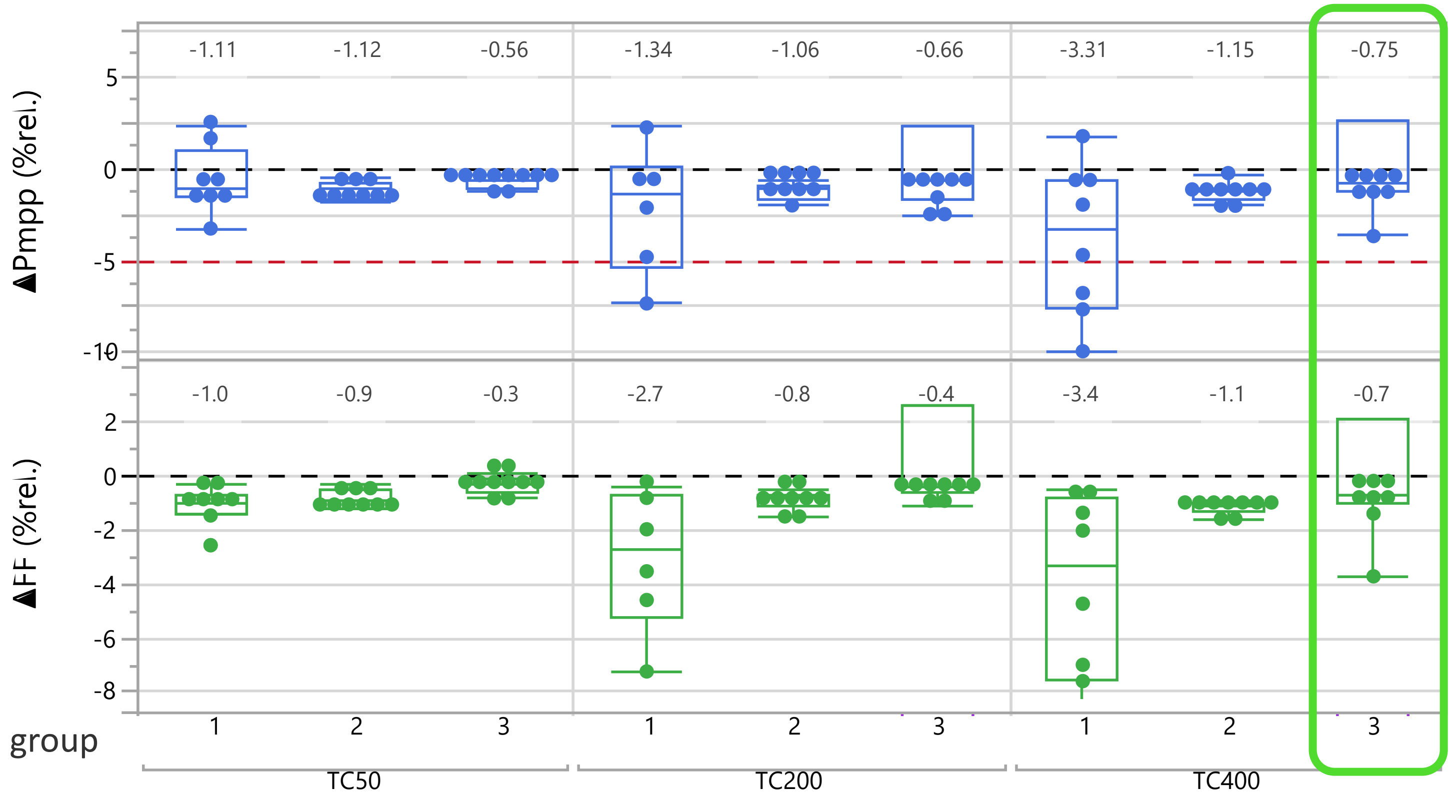
Rear bussing butterfly



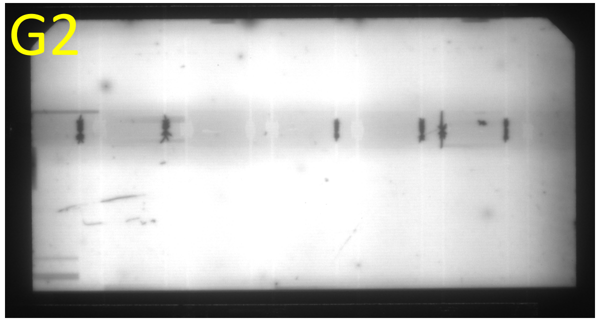
- Straightforward implementation by stringer programming (rotation vs no rotation)

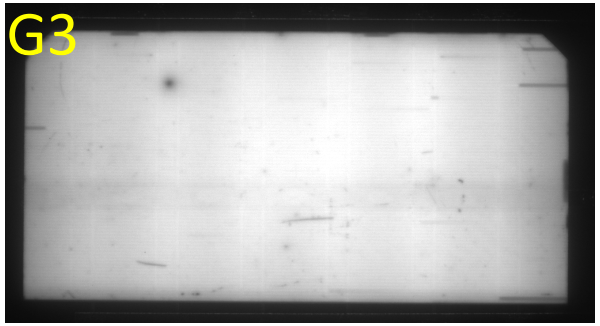
» can be used to avoid butterfly gap in IBC modules

Bussing behind cell matrix: proof of concept @ ISC



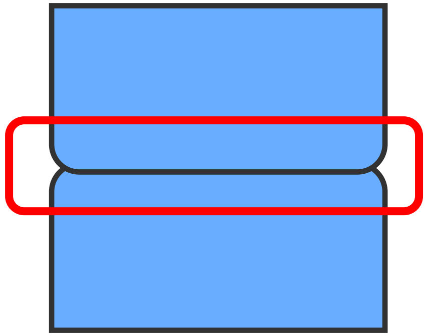
Most promising result with double isolation approach !





Technical realization of a gapless layout

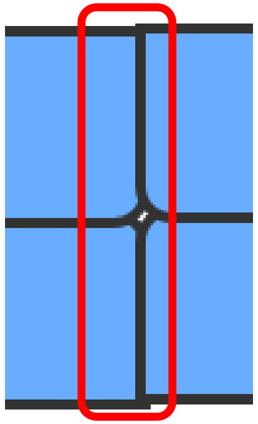
Gapless stringing



Overlap of ~0.7 mm
leads to cell shading

Adaption of stringing process

Gapless string layup



Overlap of ~1 mm
leads to cell shading

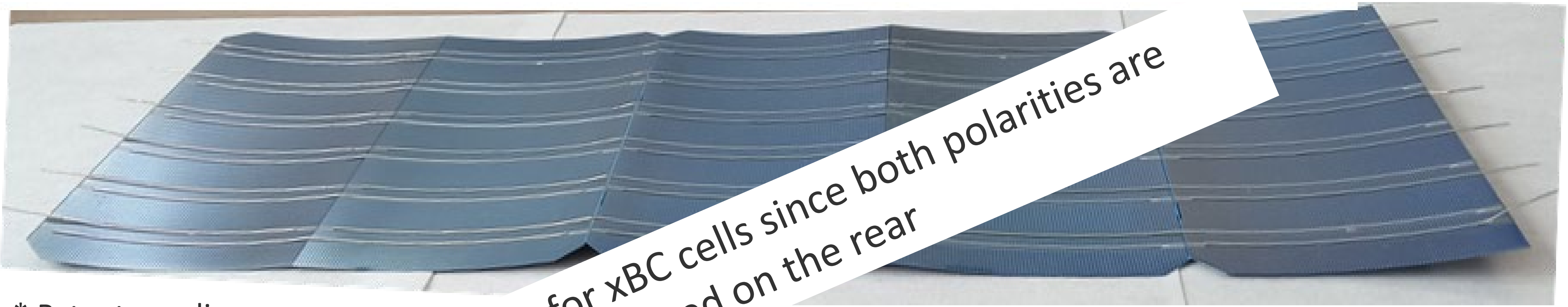
Adaption of layup process
+
Introduction of isolation layer

Gapless stringing

* Patent pending

- Small cell to cell overlap during stringing (0.5 to 1mm)
- Shadowing of cut edge reduces edge cutting losses
- No ribbon visible in cell gap
- Fully IEC 61215 certified product available at least from SPIC Solar and Aiko

Gapless stringing

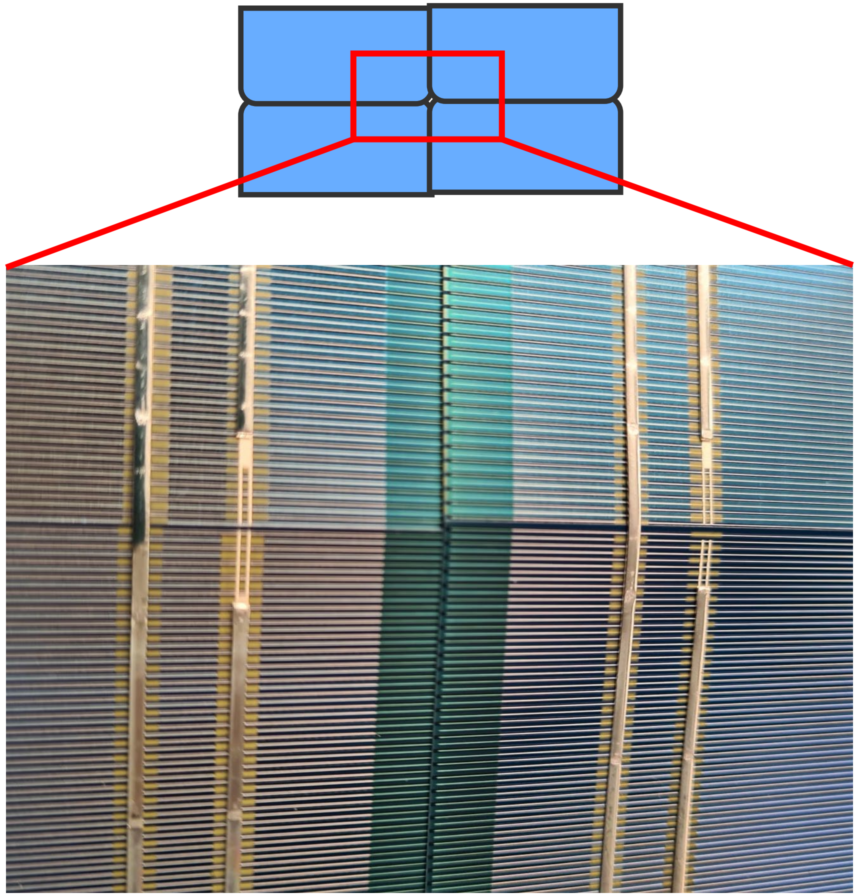


» easily possible for xBC cells since both polarities are contacted on the rear

* Patent pending

- Small cell t … uring stringing (0.5 to 1mm)
- Shadow … t edge reduces edge cutting losses
- No ribbon visible in cell gap
- Fully IEC 61215 certified product available at least from SPIC Solar and Aiko

Gapless string layup

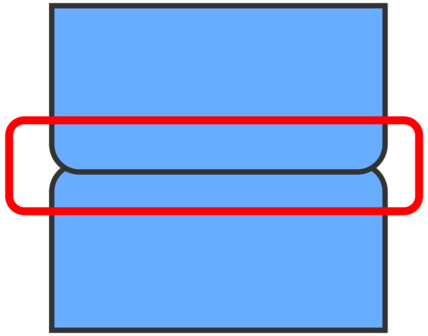


- layup realized by small offset in string direction to avoid cell buildup (4 cells, same location)
- Additional isolation layer to protect cell edges from shunting

Prototype gapless module

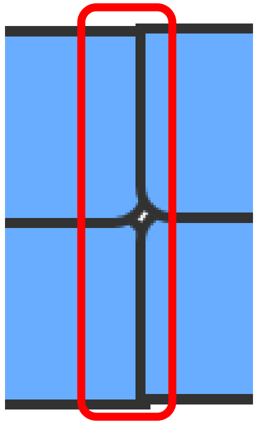
Theoretical calculation net efficiency increase for the full gapless approach

gapless stringing



Overlap of ~0.7 mm leads to **cell shading**

Gapless string layup



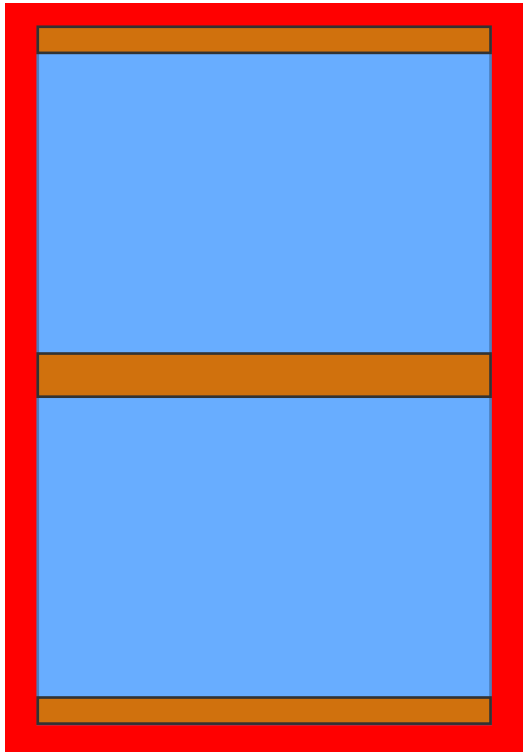
Overlap of ~1 mm leads to **cell shading**

Net efficiency increase: area reduction vs. shading

	Area reduction (%)	Shading fraction (%)
Butterfly gap and bussings	**2.8**	
Cell gaps (for 0.7 mm overlap)	**0.9 + 0.7 = 1.6**	**0.7**
String gaps (for 1 mm overlap)	**0.9 + 0.6 = 1.5**	**0.6**

» net efficiency increase for M10 HC, 54-cell module: 4.7 % rel.

Gapless module prototype: configuration



120 Zebra half cells M6

	Cell gap (mm)	String gap (mm)
reference	1	2
Gapless	-1	-2

120 Zebra half cells M6

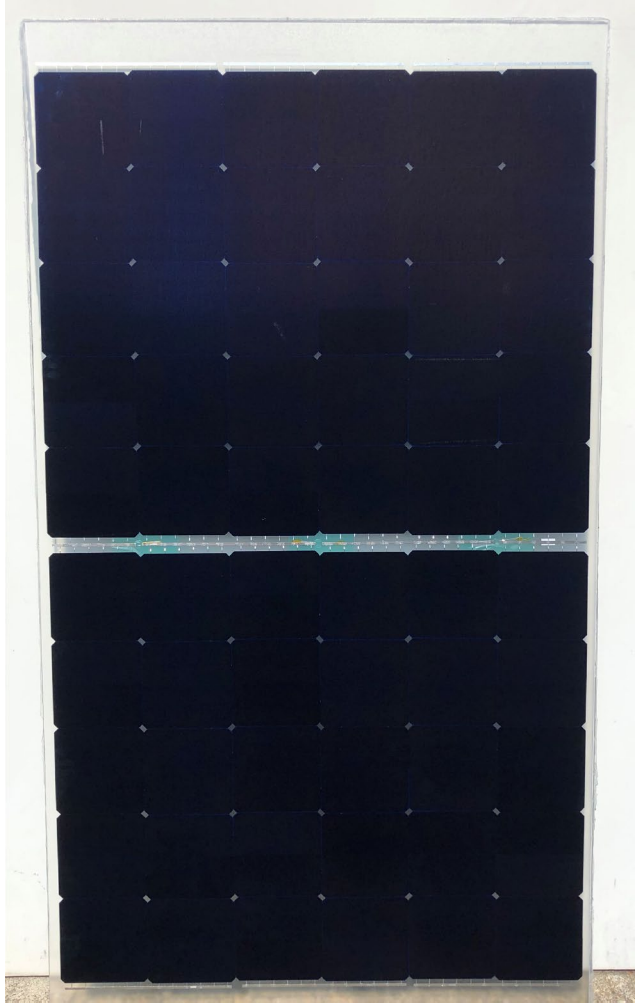
	Area reduction (%)	**Shading fraction (%)**
Cell gaps (for 1 mm overlap)	**2.1**	**1.1**
String gaps (for 2 mm overlap)	**1.9**	**2.0**

» net efficiency gain calculated: 0.9% rel.

Gapless module: IV results

	Isc [A]	Uoc [V]	FF [%]	Pmpp[W]	Eta (%)	Area (m²)
reference	11.17	41.44	79.7	369.2	20.5	1.803
Gapless	10.86	41.51	79.1	356.5	20.6	1.731
Gapless FF corrected	10.86	41.51	79.7	359.3	20.75	1.731

120 Zebra half cells M6, true bifacial, 23.1 % cell efficiency



» net efficiency gain calculated: 0.9% rel.

» net efficiency gain measured: 0.5 % rel.

» net efficiency gain FF-corrected: 0.9 % rel.

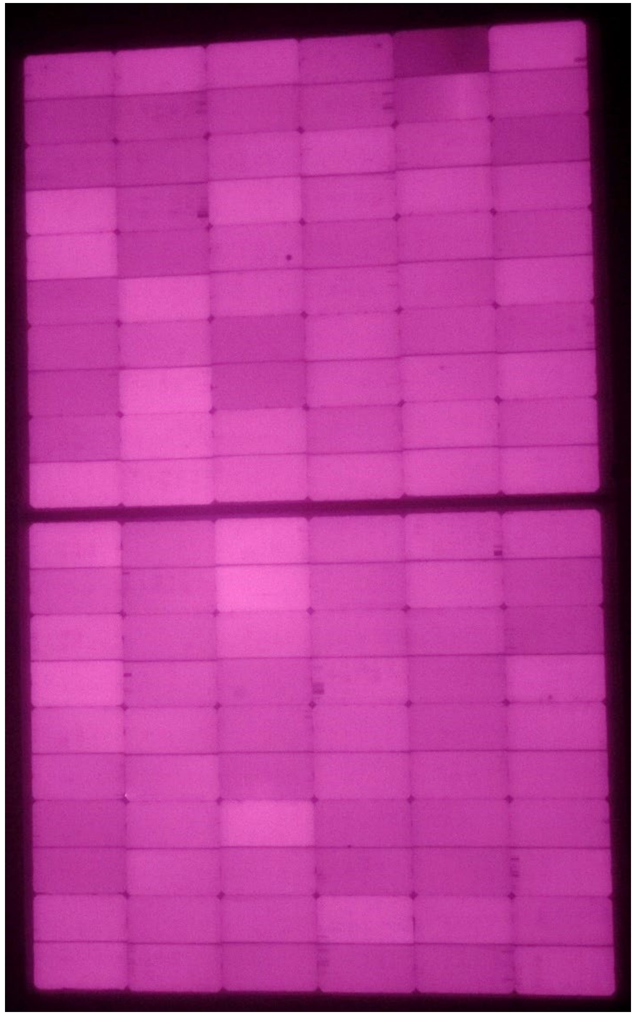
Gapless module CTM

	CTM power (%)	CTM eta (%)
reference	2.85	11.4
Gapless	6.17	10.9
Gapless (FF adapted)	5.45	10.2

120 Zebra half cells M6, true bifacial, 23.1 % cell efficiency

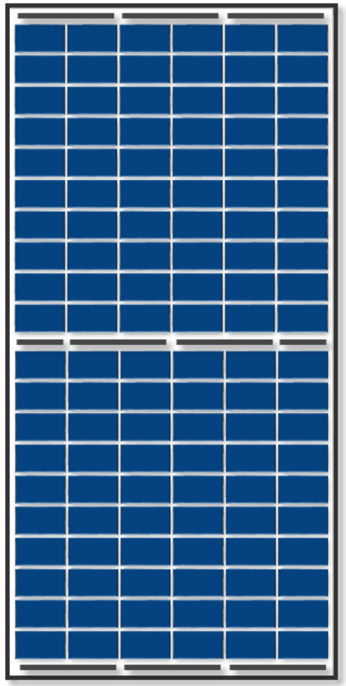
» **gapless technology improves power/area ratio !!**

CTM η ↘ **vs.** **CTM power** ↗



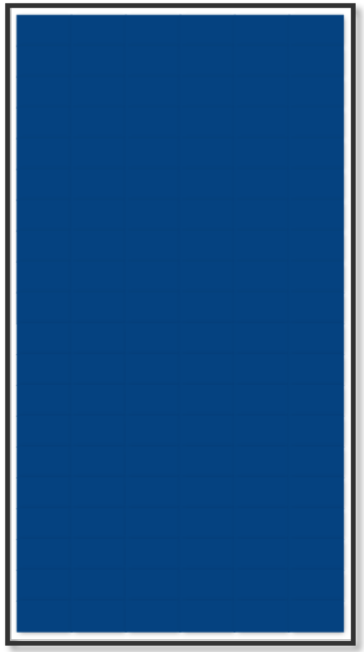
Further potential

Further potential for efficiency + power increases



470 W
23.8 %
1.76 m

*27.1% cell efficiency



464 W
25.0 %
1.65 m

*27.1% cell efficiency

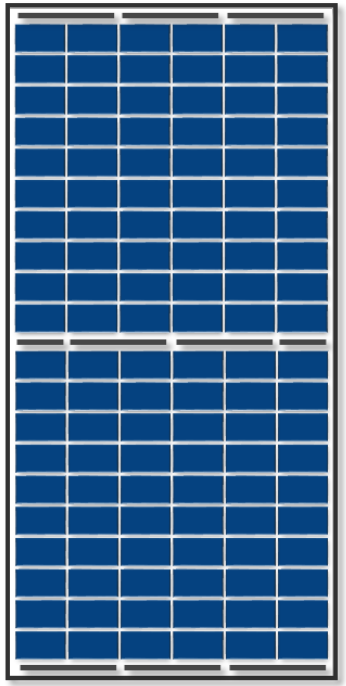
Industry standard module		
cell gap (overlap)	2	mm
string gap (overlap)	2	mm
butterfly half middle separation	30	mm
top and bottom bussing width	6	mm
top and bottom cell edge to bussing gap	4	mm
framed width	1.135	m
framed length	1.761	m
framed area	2.00	m²

Full-gapless module		
cell gap (overlap)	-0.7	mm
string gap (overlap)	-1	mm
butterfly half middle separation	-0.7	mm
top and bottom bussing width	0	mm
top and bottom cell edge to bussing gap	0	mm
framed width	1.120	m
framed length	1.659	m
framed area	1.858	m²

Further potential for efficiency + power increases

470 W
23.8 %
1.76 m

*27.1% cell efficiency



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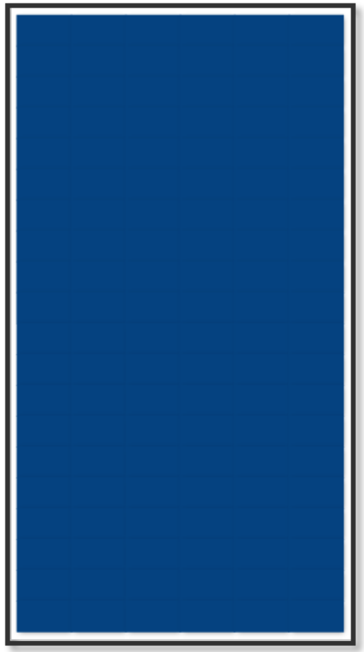
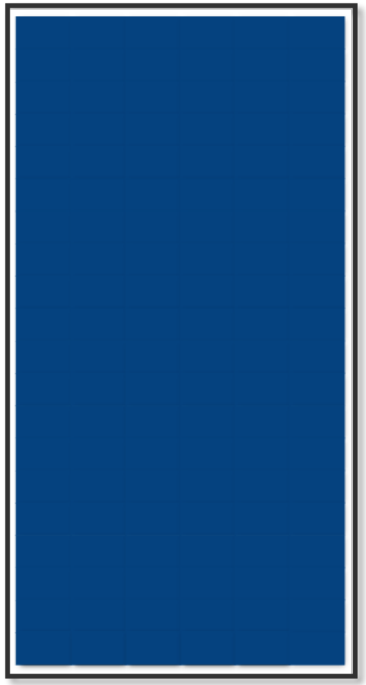


490 W
25.0 %
1.75 m

*27.1% cell efficiency



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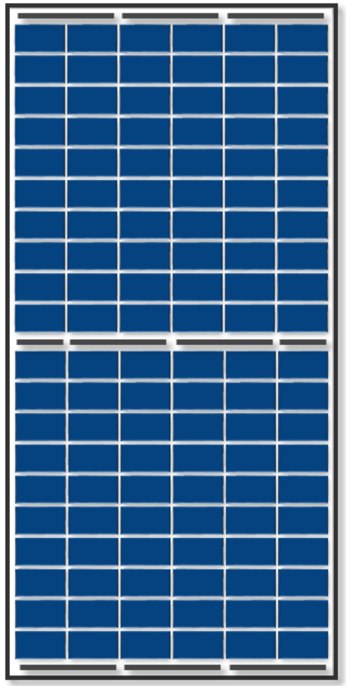
butterfly half middle separation	-0.7	mm
top and bottom bussing width	0	mm
top and bottom cell edge to bussing gap	0	mm
framed width	1.120	m
framed length	1.659	m
framed area	1.858	m²

Full-gapless +1 extra row		
cell gap (overlap)	-0.7	mm
string gap (overlap)	-1	mm
butterfly half middle separation	-0.7	mm
top and bottom bussing width	0	mm
top and bottom cell edge to bussing gap	0	mm
framed width	1.120	m
framed length	1.749	m
framed area	1.959	m²

Further potential for efficiency + power increases

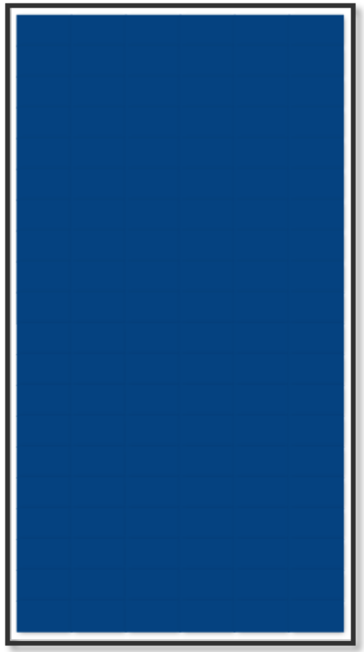
500 W
25.0 %
1.76 m

***28.4%** cell efficiency



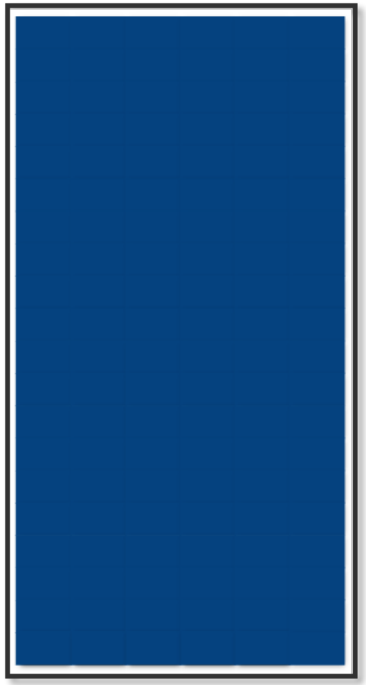
464 W
25.0 %
1.66 m

*27.1% cell efficiency



490 W
25.0 %
1.75 m

*27.1% cell efficiency



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top and bottom cell edge to bussing gap	4	mm
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framed length	1.761	m
framed area	2.00	m²

Full-gapless module		
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top and bottom cell edge to bussing gap	0	mm
framed width	1.120	m
framed length	1.749	m
framed area	1.959	m²

Summary

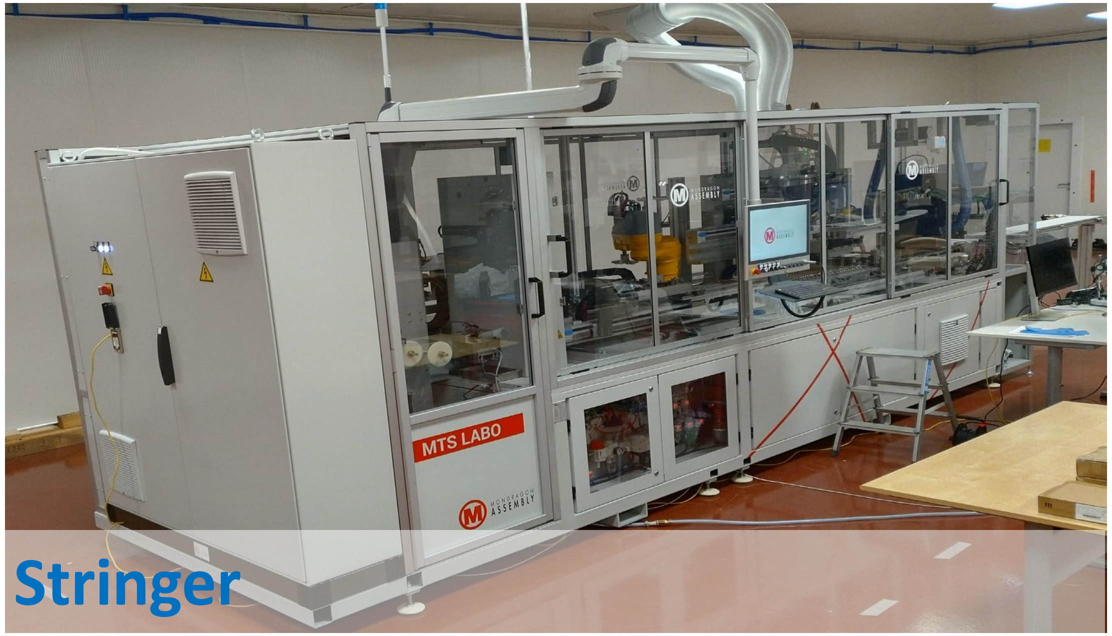
- Theoretical potential to reduce inactive module area was shown with potential efficiency increase 4.7%rel.
- Proof of concept done for implementation with xBC cells
  - Bussing behind cell matrix
  - Gapless stringing
  - Parallel/series combined stringing
  - Full gapless layout
- Combination of all concepts and process optimization pending

IBC4EU

This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement No.101084259

Building the Future Lab – Together

Wet benches



Stringer

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