SUNOVATION

SUNOVATION
the BIPV company

Erban, C. - Module design based on BC PV cells

Christof. Erban at - 10th BCworkshop 2022, Konstanz

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aufgrund eines Beschlusses des Deutschen Bundestages

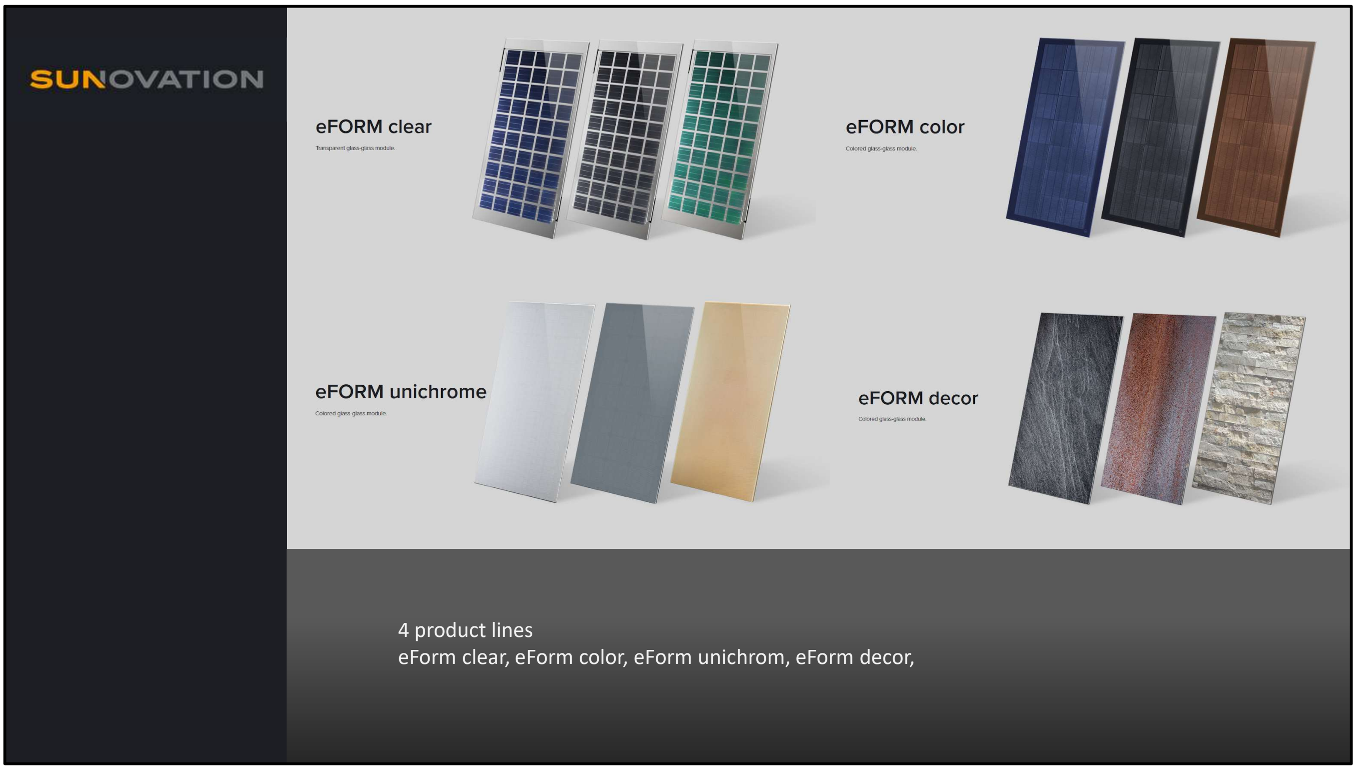
FKZ: Z-Quadrat 03EE1005C

22nd November 2022

SUNOVATION

- Development and manufacturing of multifunctional BIPV elements for the building envelope
- Unique production technology for the embedding of solar cells and electrical components
- Product development and manufacturing since 2001
- 65 employees (by 2019)
- Factory in Aschaffenburg (near Frankfurt airport)

MADE IN GERMANY



Sunovation is able to manufacture solar modules from

Size: 20 x 30 cm up to 250 x 400 cm
Format: any shape is possible: rechtangular, trapezoidal, round, eliptic, etc.

4 product lines:
eForm clear: 2 clear glass panes, standard mono- or bifacial solarcells thatmay be colored
eForm: color: 2 glass panes with the rear on colored to match or be a contrast to the cell color
eForm unichrome: 2 glass panes with the front glass uniformly colored to generate a unform color appearance
eForm decor: 2 glass panes with the front glass uniformly colored to generate a patter/ design of choice

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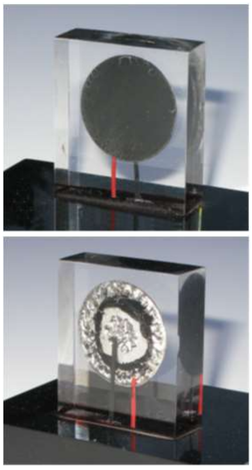
Once upon a time…

25.4.1954, David Chapin, Calvin Fuller und Gerald Pearson



n-type
IBC
Bifacial
colored

Source: Bell Laboratories, cell images by C.Erban

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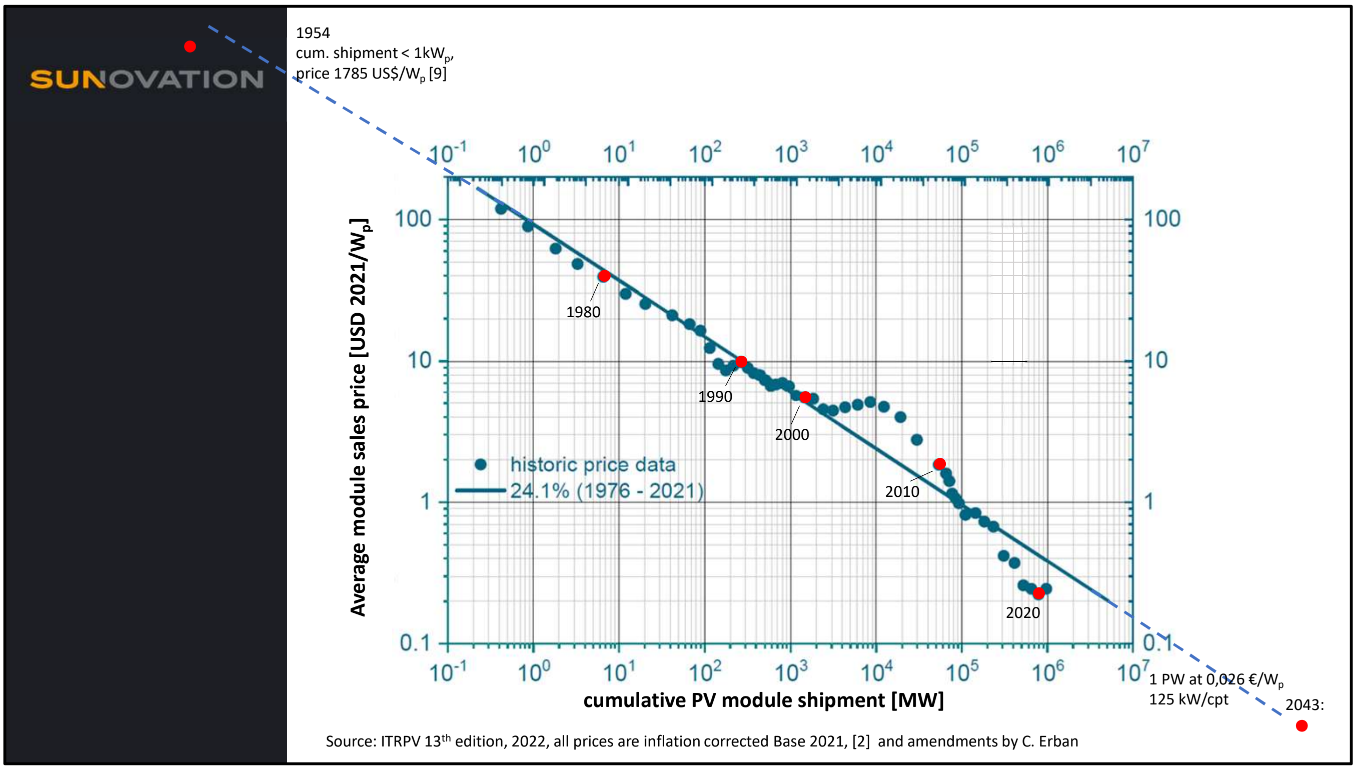
Once upon a time…

1955, a rural telephone system in Americus, Georgia

array of 48 PV modules each containing 9 cells to charge a 20 volt storage battery
6 strings of 72 cells → η = 3,5%

Source: Chapin, D. M., Energy from the sun, Bell Telephone Laboratories, 1962



It took until 1977 – thus around 23 years - since the invention of the silicon solar cell in 1954 - for the first MW to be produced. Then it took about 20 years until the 1 GW was produced. (1977 - 1997) Then it took about 24 years until the 1 TW was produced. (1997 - 2021) . 1 TW corresponds to 125W/cpt. There seem s to exist a pattern of 20 years for the cumulated power to increase by three magnitudes.

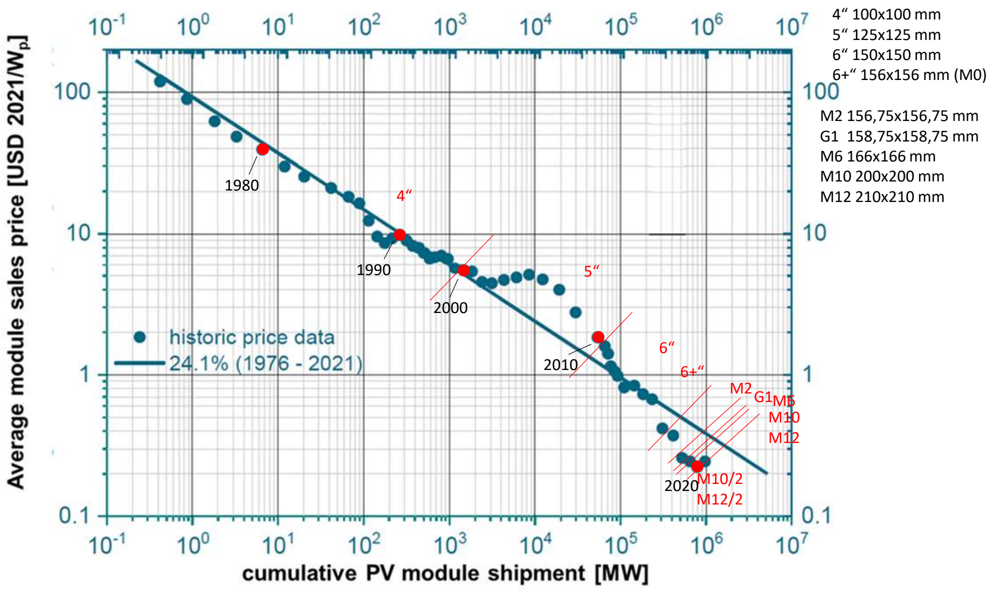
Extending this learning curve towards the beginning of the silicon solar era. The graph is still valid as can be seen for the properties given for 1954

Extrapolating the curve to the future with the given data for today:
1 TeraW at 26€c; → 0,003% of the land mass is covered and every inhabitant owns 125W/cpt

-> Assumption: this time pattern will continue and every 22 years, the cumulated pv power of one PetW will be installed around 2044

With one PTW installed PV will costs 2,6€c → 7,2 US$ per 300 Wp solar module. 1PW will cover 3,2% of the land mass is covered and every inhabtant owns 125kW/cpt
Both - 7,2 US$ per 300 Wp solar module and 125kW/cpt - are very unlikely to happen→ the linear curve will flatten and become a hockey stick like curve

price-learning rate and cell dimensions



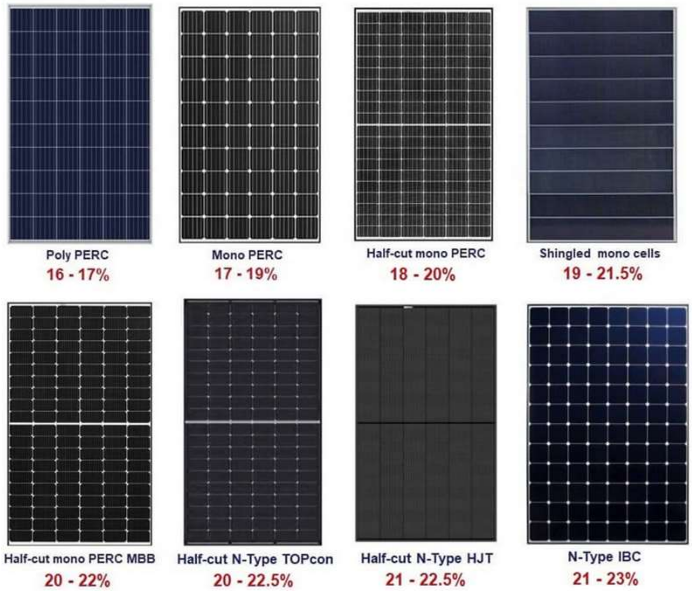
Source: ITRPV 13th edition, 2022, all prices are inflation corrected Base 2021, amendments by C. Erban

For decades the cell sizes remained identical:

- Before 1975 most solar cell had sizes of ≤ 3“.
- Roughly 25 years until 2000 cells were around 4“either round or square
- Roughly 12 years until 2012 cells were around 5“either pseudo square (mono) or square (multi)
- Roughly 8 years until 2020 cells were around 6“ or 6+“either pseudo square (mono) or square (multi)

- Then in a short time a multitude of cell sizes and shaped occured

Solar module designs of the 2020ies



Source: https://www.cleanenergyreviews.info/blog/most-efficient-solar-panels

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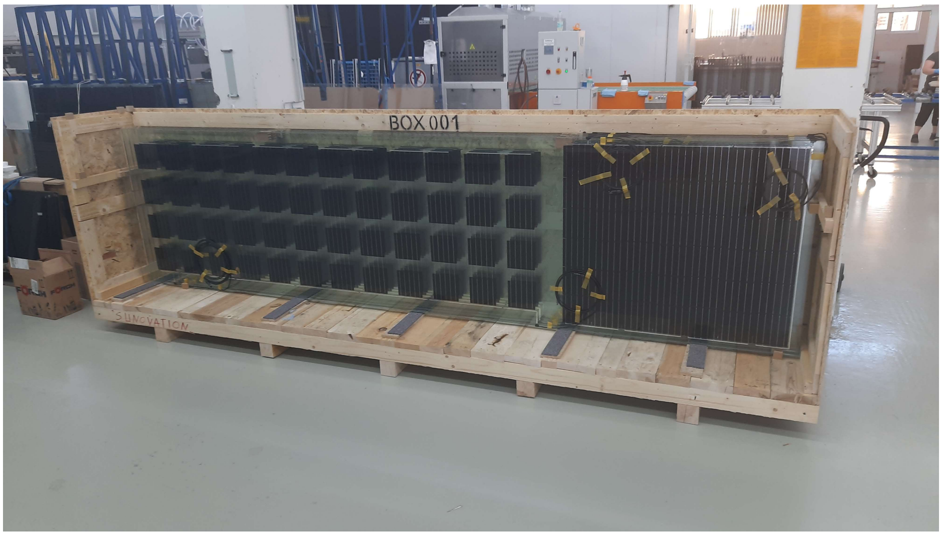
SUNOVATION module designs of the 2020ies



Glass dimensions: 4190 x 1042
Electrical properties:

Two separate electrical circuits:
left 7 x 6 = 42 cells
P_{MPP}: 223 W_P
V_{OC}: 28,8 V
I_{SC}: 9,7 A

right 12 x 4 = 48 cells
P_{MPP}: 255 W_P
V_{OC}: 32,9 V
I_{SC}: 9,7 A

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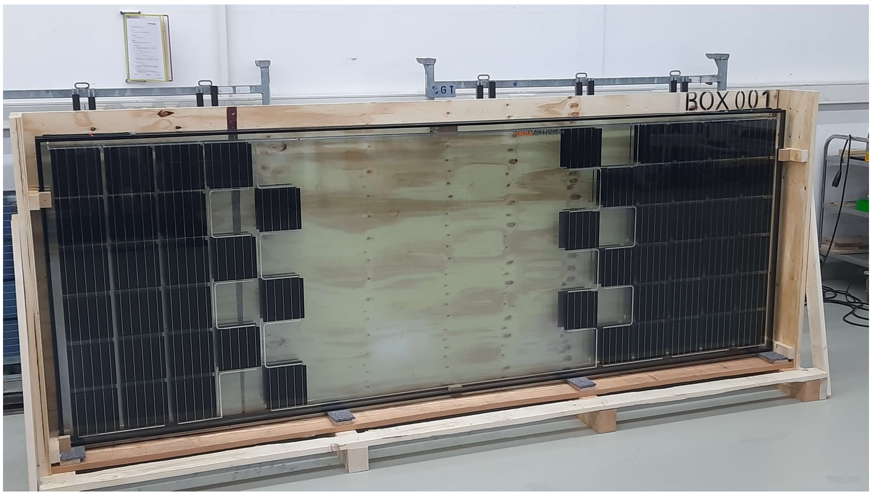
SUNOVATION module designs of the 2020ies



Glass dimensions: 3086 x 1116
Electrical properties:

One single electrical circuit:
42 cells
P_{MPP}: 287 W_P
V_{OC}: 37 V
I_{SC}: 9,7 A

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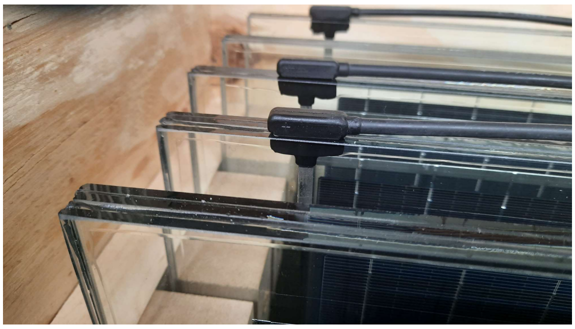
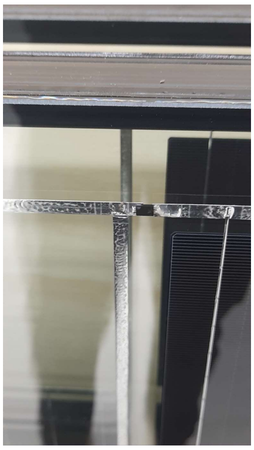
SUNOVATION module designs of the 2020ies





Edge connector: connect 7
Integrated bypass diode

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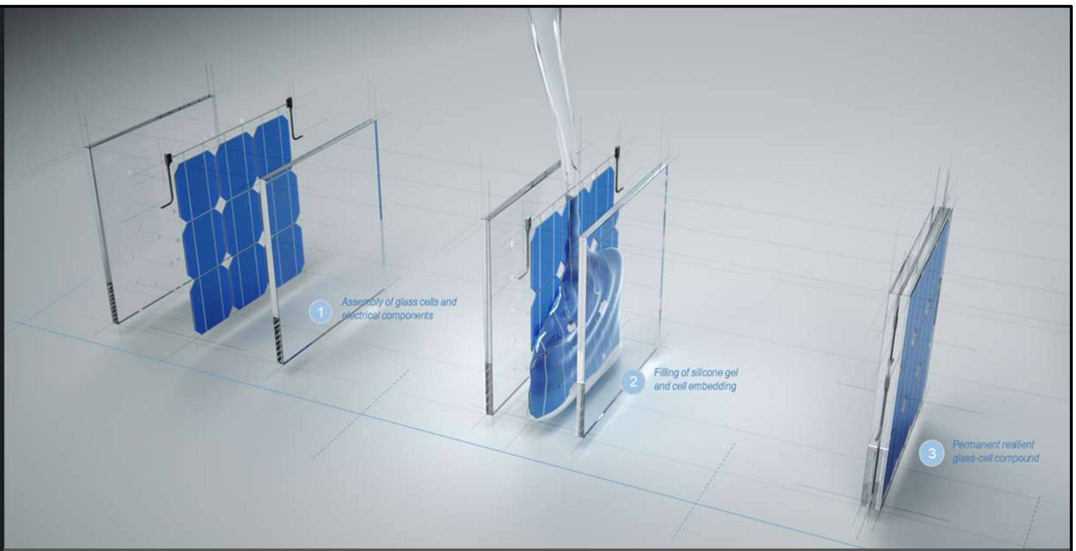

UNIQUE TECHNOLOGY:
Filling of liquid silicone gel between glass layers to embedd cells

* SCET and the particular 2K Gel, used for this procedure are
proprietary and protected technologies of SUNOVATION Produktion GmbH

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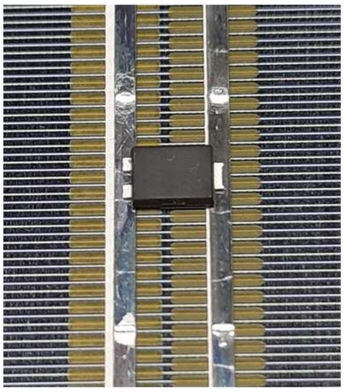
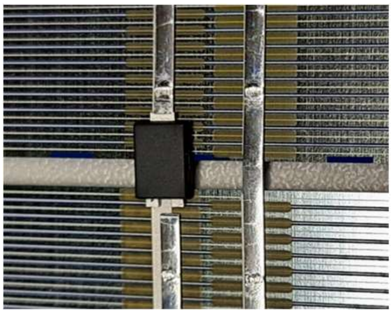
Integrated bypass diode in IBC modules (detail)





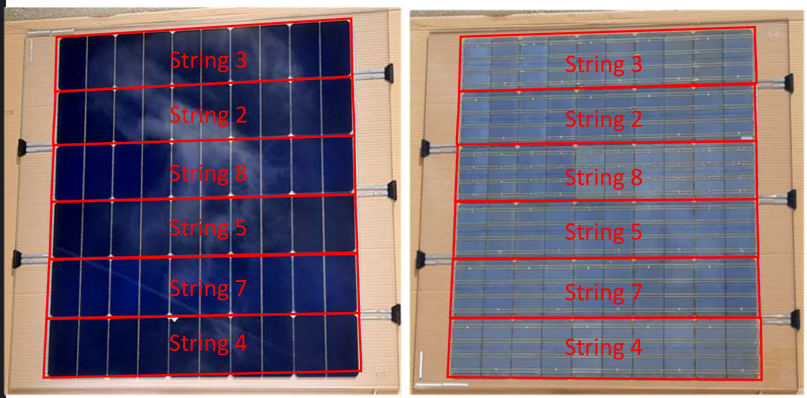
Bypass diode setup on the rear of ZEBRA solar cells investigated in the Z² project

Left: one diode per cell
Right: one diode per two adjacent cells

(Note: both images show the non connected bypass diodes to illustrate their psoition

Integrated bypass diode in IBC modules (setup)

6 strings of 10 ZEBRA halfcut M2



String 3: 0 diodes

String 2: 0 diodes

String 8: 1 diode/ cell

String 5: 4 diodes/ cell

String 7: 1 diodes/ 2 cells

String 4: 4 diodes/ 2 cells

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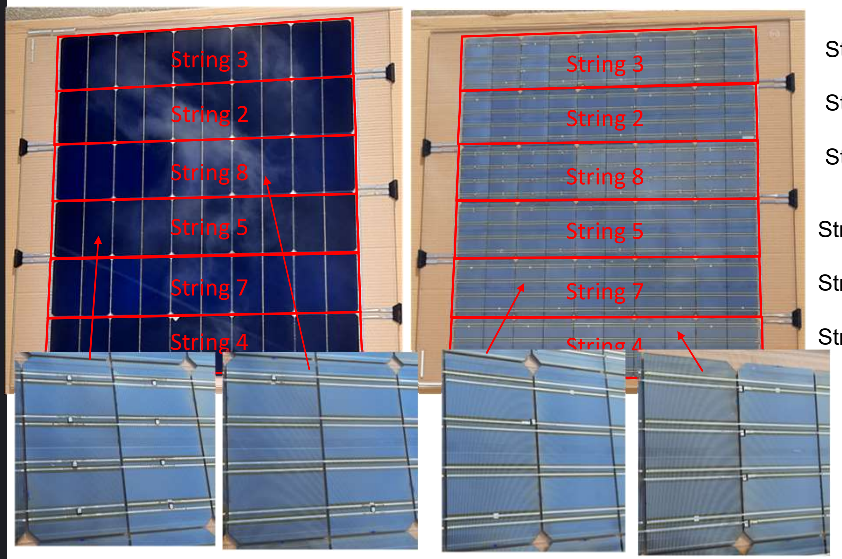
Integrated bypass diode in IBC modules (as built)



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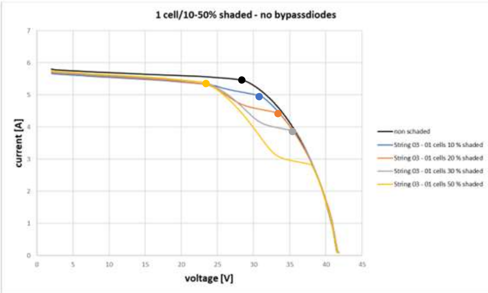
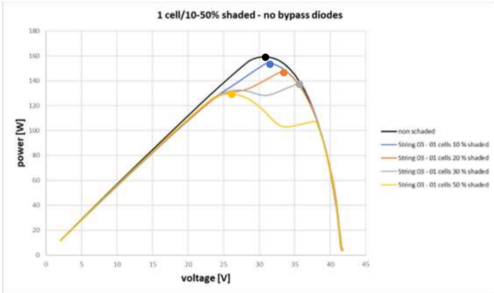
Shading of IBC cells





The graphs show IV and PV curves for a pv module which **does not** contain a bypass diode and in which one cell is 10%, 20%, 30 and 50% shaded :

Takeaway 1:
Shading may result in two distinct MPPs that differ in voltage and current
Takeaway 2:
The inverter defines the operation point of the pv panel according to the $P_{max.}$
Takeaway 3:
In this specific setup: 1 Module measured alone: the 10%, 20% and 30% shading results in a current loss of the entire module: the weakest cell defines the overal module current→ all cells are operating in the first quadrat. No revers voltage of a single cell.
In contrast the 50% shading results in a new MPP which has a lower MPP voltage. The voltage loss is equivalent to the breakthrough voltage of appr. -5V of the shaded cell. This cell is operating in the second quadrat and will be hot.

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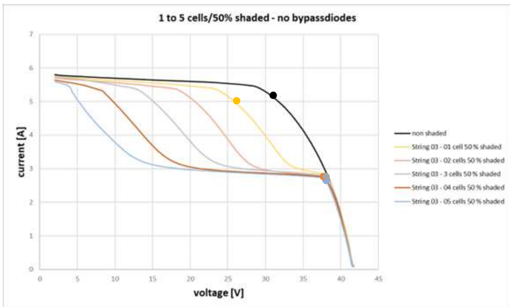
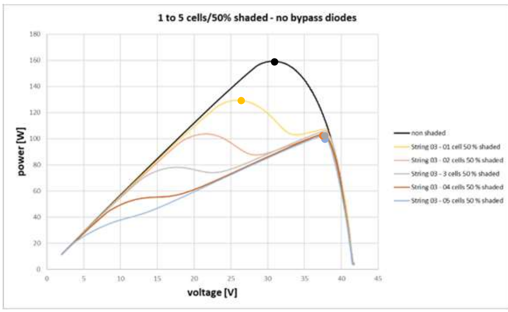
Shading of IBC cells





The graphs show IV and PV curves for a pv module which **does not** contain a bypass diode and in which one to five cells are shaded 50% :

Takeaway 1:
Severe shading of mutiple solar cells may result in differing MPP‘s that differ in voltage and current
Takeaway 2:
With increasing number of shaded cells the voltage significantly decreases.
Takeaway 3:
In this specific setup: 1 Module measured alone: the shading of more than one cell in the module causes a voltage and power loss that is so severe that the inverter will mainain the Module MPP at the MPP of the shaded cells. In this case no cell will be operating in the second quadrant and no cell will be hot.

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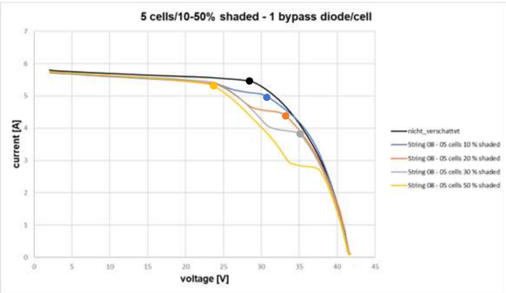
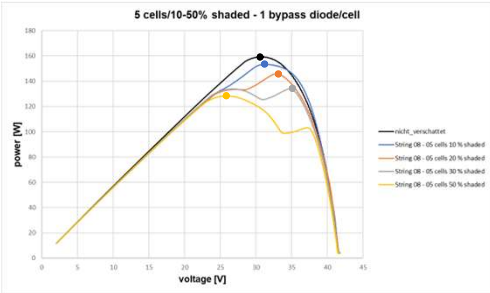
Shading of IBC cells





The graphs show IV and PV curves for a pv module which **does** contain a bypass diode per cell and in which one to five cells are shaded from 10 to 50% :

Takeaway 1:
The IV curves of 5 cells with bypassdiode look almost identical to the IV curves of 1 cell without bypassdiode.
Takeaway 2:
One cannot distinguish between the reverse IV of one ZEBRA cell without diode compared to five cells with diode.
Takeaway 3:
Since the cells are protected by their own specific bypassdiode the cells will not be hot → from the IV curve measurements one cannot immediatly draw a conclusion on the operating point of the solar cells or their temperature if the bypass diode setup is not provided in detail.

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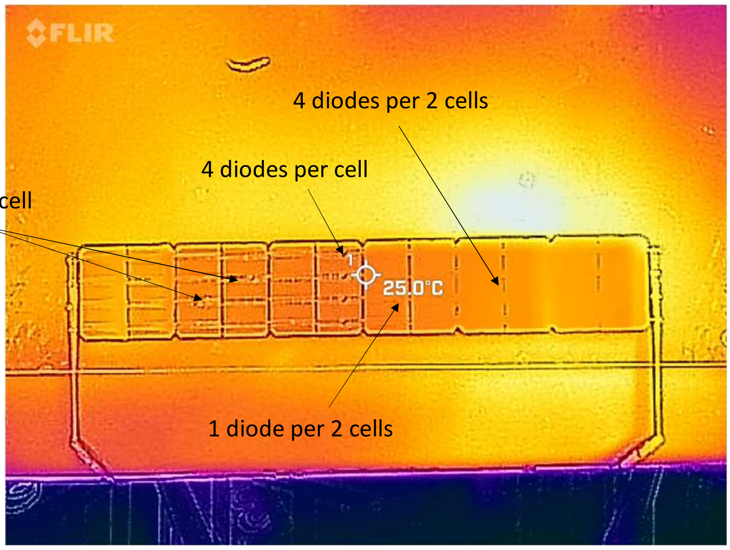
Shading of IBC cells 5 A reverse current, 0 irradiance, 22 °C ambient temperature



Start of measurement

hot cells ≈ 121°C cold cells ≈ 20 °C in the area
40°C close to bypassdiodes
diode temp ≈ 40-55°C

Pos: (left to right)	voltage drop per cell	power dissipation per cell	cell temperature
cell 1:	5,15V	25,75 W	≈ 120°C
cell 2:	5,2V	26,0 W	≈ 120°C
cell 3:	0,38/0,33/0,56/0,61V	≈ 2 W	≈ 48°C
cell 4:	0,61/0,57/0,31/0,38V	≈ 2 W	≈ 42°C
cell 5:	5,18V	25,9 W	≈ 114°C
cell 6:	0,27/0,29/0,27/0,26V	≈ 1,4 W	≈ 40°C
celln 7/8:	0,32V	≈ 1,6 W	≈ 33°C
celln 9/10:	0,27/0,27/0,29/0,27V	≈ 1,4 W	≈ 40°C
cell 11:	5,1V	25,5 W	≈ 121°C
cell 12:	5,22V	26,1 W	≈ 120°C

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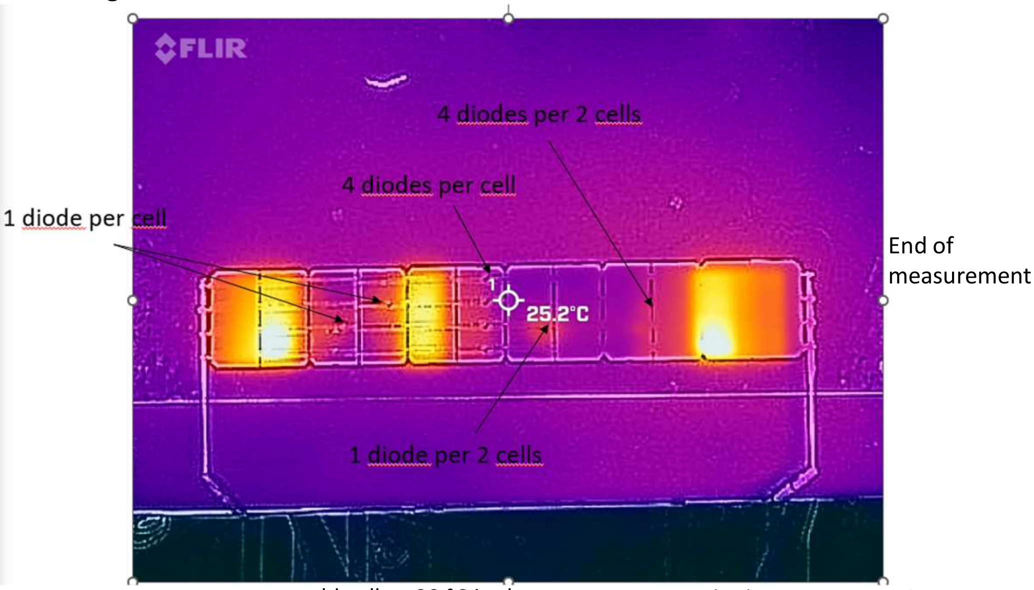
Shading of IBC cells 5 A reverse current, 0 irradiance, 22 °C ambient temperature



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celln 7/8:	0,32V	≈ 1,6 W	≈ 33°C
celln 9/10:	0,27/0,27/0,29/0,27V	≈ 1,4 W	≈ 40°C
cell 11:	5,1V	25,5 W	≈ 121°C
cell 12:	5,22V	26,1 W	≈ 120°C

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BIPV color design modules of the 90ies

A solar facade installed in late 1990ies at the cultural centre in Konstanz that contains silver 4“ multicrystalline cells.

CTM is apr. 120% since the original solar cells did not contain any AR coating thus the embedding extremely improved the originally extremely high reflection losses.

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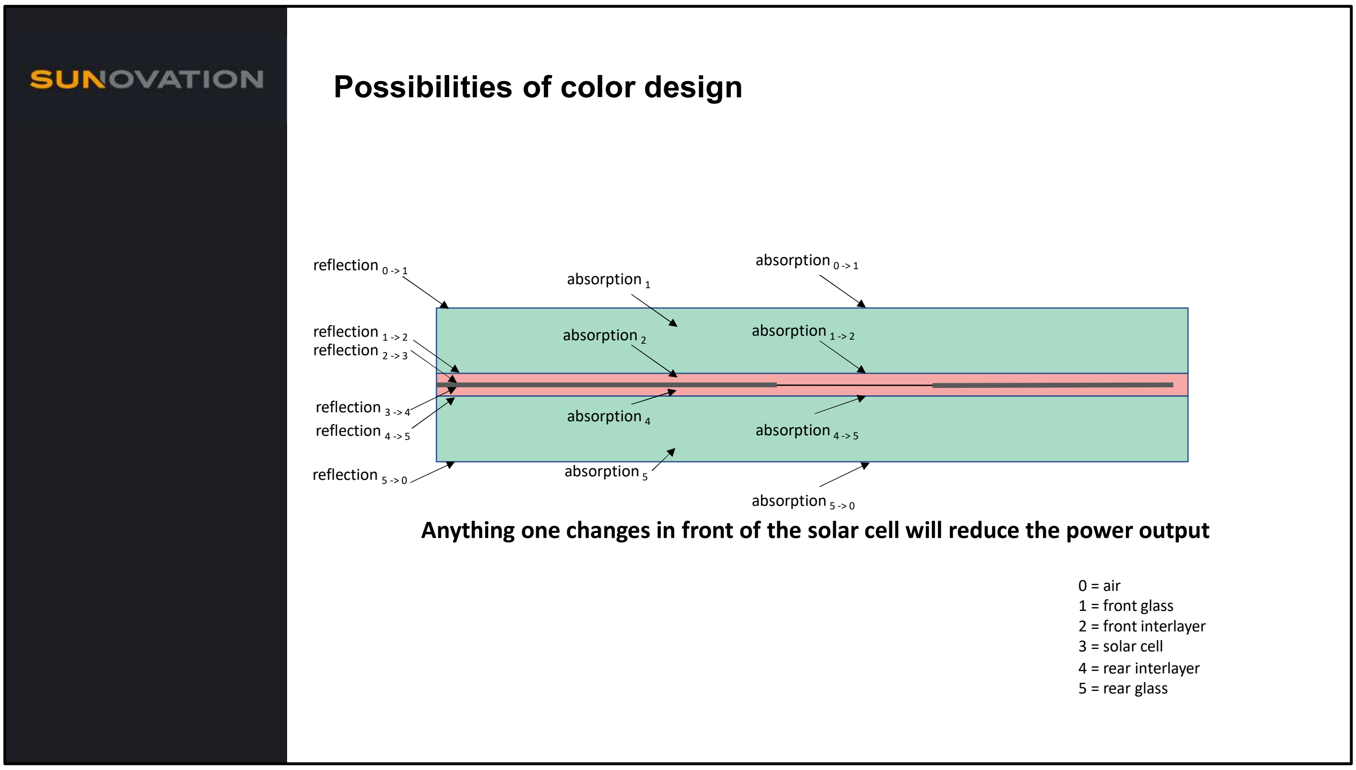
SUNOVATION color design modules of the 20ies



The graph describes at which location and by which optical principle color can be added in front of the solar cell.

One can either

- Modify the reflection on one or more of the surfaces of each material used in front of the cell or
- by modification of the absortion of the bulk material or
- by adding addiditonal absorption on the surface of each material.

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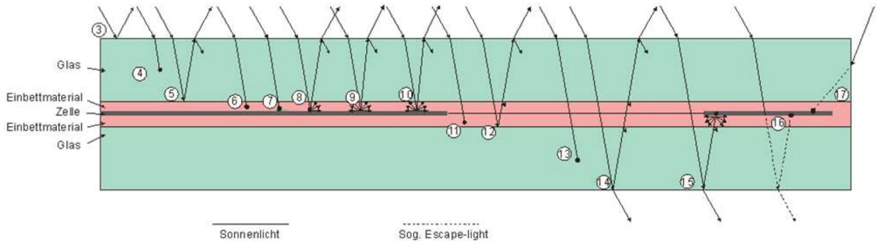
Loss mechanisms of glass-glass pv modules



Source: K. Mc Intosh PV Lighthouse, addednum by C Erban for the 44th IEEE PVSC tutorial on BIPV

In case the solar cells are used in a bifacial module all effects shown are likewise present from the bottom.

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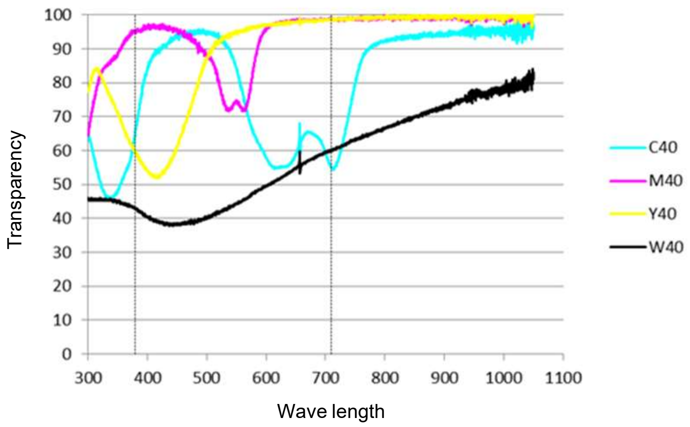
Transparency of absorption colors



Source: Erban, C., The “invisible-solar-panel” - colored photovoltaic panels with high efficiency, PowerSKIN, RWTH Aachen, 2022

In case the color of the solar module is obtained by a translucent printing with absorption pigments one looses a signficant amount of electricity since the pure color on ist own will not be visible in front of the solar cells as long as it is not backup up by a white backlayer. The total loss results from the transparency of the color and its white backup behind.

Dense printing with absoption colors can result in very high power losses.

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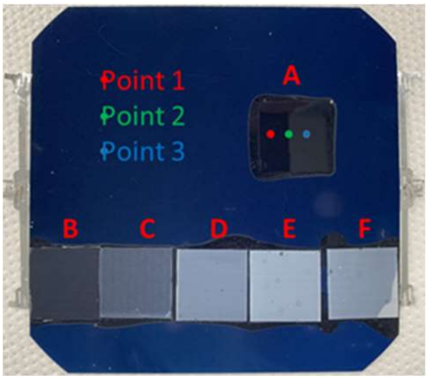
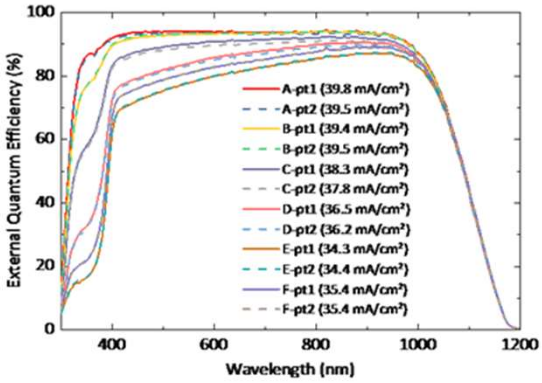
Effect on EQE induced by absorption colors





Source: Erban, C., The “invisible-solar-panel” - colored photovoltaic panels with high efficiency, PowerSKIN, RWTH Aachen, 2022

Broadband reduction of the EQE caused by an white printing with increasing density of absoption pigments on the front glass.

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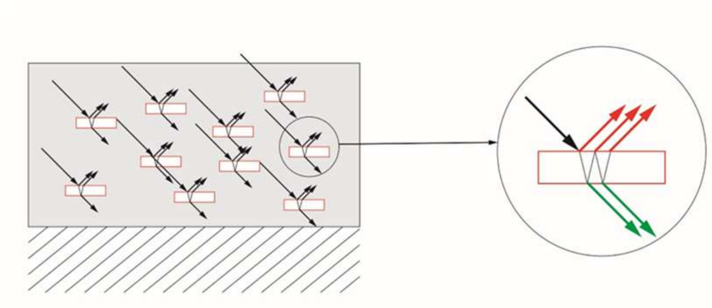
Principle of pearl effect pigments



Source: Erban, C., The “invisible-solar-panel” - colored photovoltaic panels with high efficiency, PowerSKIN, RWTH Aachen, 2022

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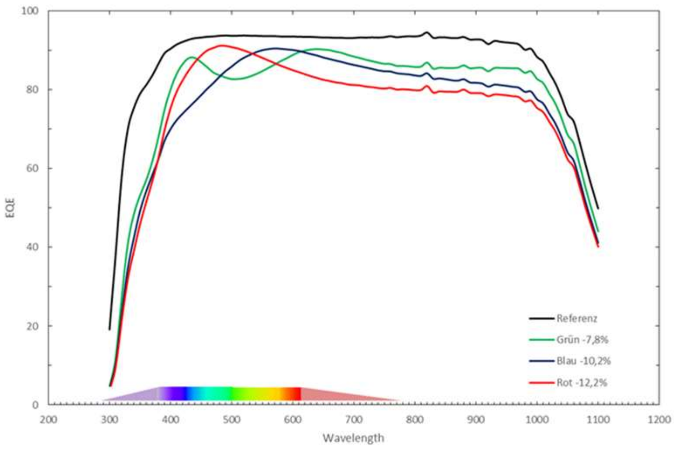
Effect on EQE induced by interference colors



Source: Erban, C., The “invisible-solar-panel” - colored photovoltaic panels with high efficiency, PowerSKIN, RWTH Aachen, 2022

Effect pigments will reduce the power output only slightly since all other colors will be transmitted and can thus conribute to the electricity generation of the solar cell.

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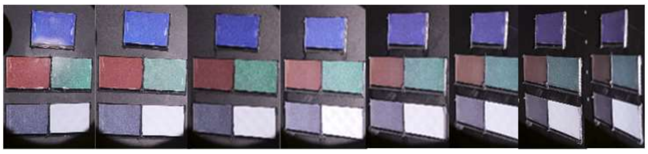
Angle stability of effect pigment colors

Series of photographs of color sample blue, red, green , dark gray, light gray taken from 9 different azimuth angles (0° left to 80° right) at natural daylight



Series of photographs of color sample blue, red, green, dark gray, light gray taken from 8 different azimuth angles (10° left to 80° right) at direct sunlight

Source: Erban, C., The “invisible-solar-panel” - colored photovoltaic panels with high efficiency, PowerSKIN, RWTH Aachen, 2022

The use of effect pigments leads to colors that have a high angle stability.

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und Energie

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des Deutschen Bundestages

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