Bifacial IBC (ZEBRA) technology

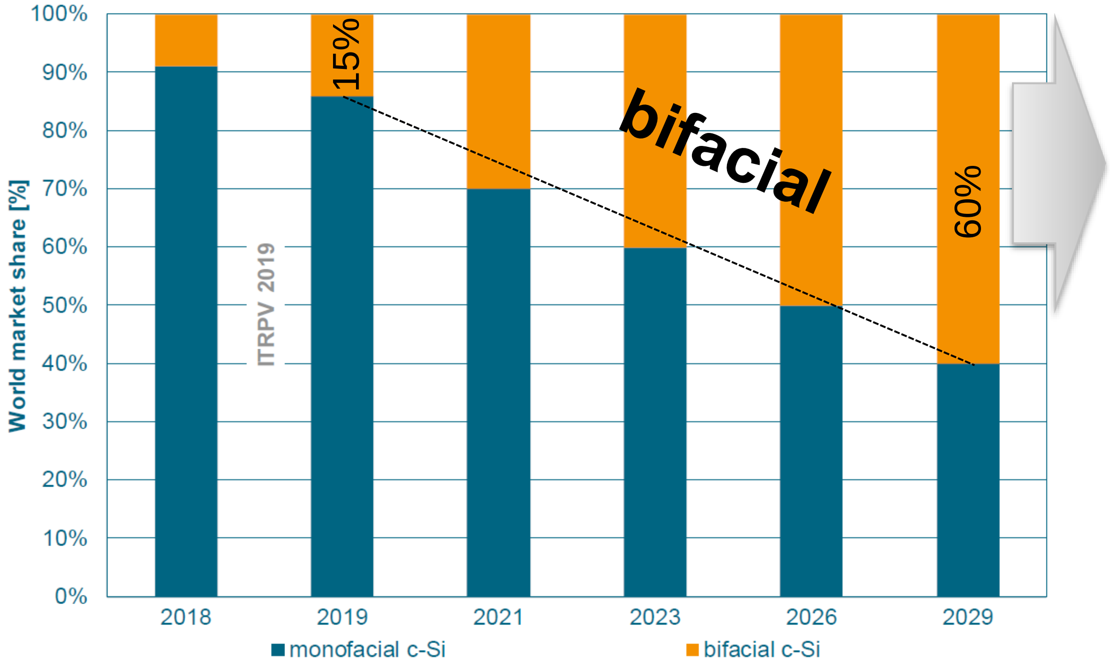
Valentin Mihailetchi[1], Andreas Halm[1], Haifeng Chu[1], Joris Libal[1], Radovan Kopecek[1]
Ma Jikui[2], Liu Jianda[2], Guo Yonggang[2], Dong Peng[2]

6th bifiPV workshop, Amsterdam, The Netherlands

[1] International Solar Energy Research Center e.V., Konstanz, Germany
[2] SPIC Xi'an Solar Power CO. LTD., China

ITRPV roadmap

Bifacial cells in the world market



Cell technologies fit for bifacial:

PERx (incl. passivated contacts)

- » >50% market share
- » on *p*- and *n*-type

Si- Heterojunction (SHJ)

- » ≈2% market share
- » on *n*-type only

Back contact (IBC)

- » ≈2% market share

Si- Tandem

- » expected from 2023

***Data from:* International Technology Roadmap for PV, 2019**

Bifacial cell technologies

International Solar Energy Research Center Konstanz

Overview and performance of industrial bifacial cell technologies*

Cell concept	Bifaciality factor (on cell level)	Si base material	Junction and BSF doping method	Contacts	(Front) Efficiency potential
Heterojunction	>92%	n mono	a-Si:H p- and n-type doped	TCO/Ag printed TCO/Cu plated	22%–25%
n-PERT	>90%	n mono	Boron and Phosphorous diffusion	Ag and Ag/Al printed	21%–22%
p-PERT	>90%	p mono	Phosphorous and Boron diffusion	Ag and Ag/Al printed	21%–22%
PERC+	>80%	p-mono	Phosphorous diffusion and local Al BSF	Ag and Al printed	21%–22%
IBC	>70%	n-mono	Boron and Phosphorous diffusion	Ag and Ag/Al printed	22%–23%

High BF (bifaciality factor):

- » suited also for east/west vertical installations
- » Cell performance could be optimized for both side illumination

Moderate BF:

- » Cell performance optimized for front side illumination

* Bifacial Photovoltaics, ISBN 978-1-78561-274-9 (2018)

Bifacial cell technologies

International Solar Energy Research Center Konstanz

Overview and performance of industrial bifacial cell technologies*

Cell concept	Bifaciality factor (on cell level)	Si base material	Junction and BSF doping method	Contacts	(Front) Efficiency potential
Heterojunction	>92%	n mono	a-Si:H p- and n-type doped	TCO/Ag printed TCO/Cu plated	22%–25%
n-PERT	>90%	n mono	Boron and Phosphorous diffusion	Ag and Ag/Al printed	21%–22%
p-PERT	>90%	p mono	Phosphorous and Boron diffusion	Ag and Ag/Al printed	21%–22%
PERC+	>80%	p-mono	Phosphorous diffusion and local Al BSF	Ag and Al printed	21%–22%
IBC	>70%	n-mono	Boron and Phosphorous diffusion	Ag and Ag/Al printed	22%–23%

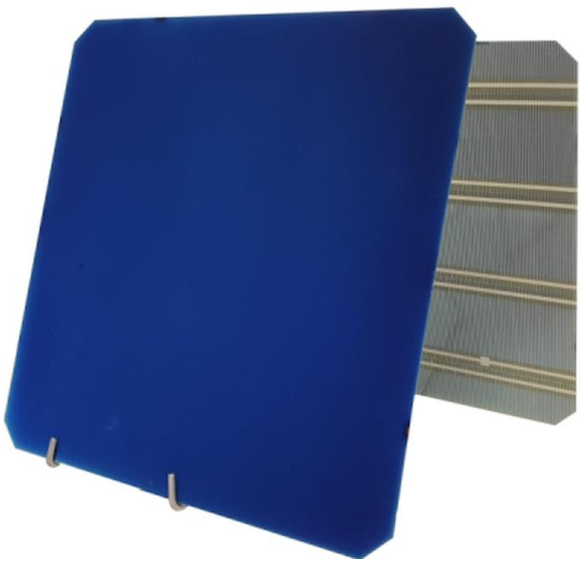
Outline:

ZEBRA concept, updated IV results, cell bifacial simulations, module concept

* Bifacial Photovoltaics, ISBN 978-1-78561-274-9 (2018)

ZEBRA: key features

ZEBRA (IBC) bifacial low cost cell concept by ISC Konstanz



Photograph of the front and back sides (mirrored)

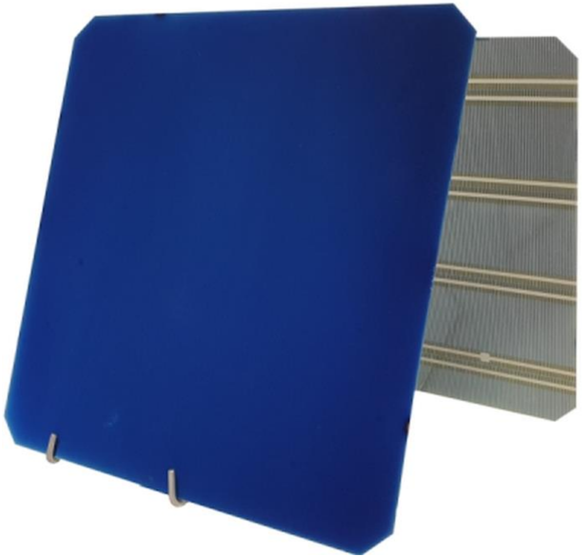
Key features:

- n-type Cz wafers (M2 or larger)
- a BBr_3 and a $POCl_3$ (**homogeneous**) diffusion
- **in-situ SiO_2** / SiN_x passivation and ARC[1]
- screen printed and **firing-through** contacts[2]
- Bilayer (3D) interconnection of fingers
- 4 BBs (or more) design → suitable for conventional stringing methods
- ramp-up/production of 200 MWp started at SPIC (China)
- planed ramp-up/production in EU by Valoe/Solitek (Lithuania)

[1] V.D. Mihailetchi *et al.*, IEEE J. Photovolt. 8, p.435 (2018)
[2] V.D. Mihailetchi *et al.*, IEEE 7th WCPEC p.2673 (2018)

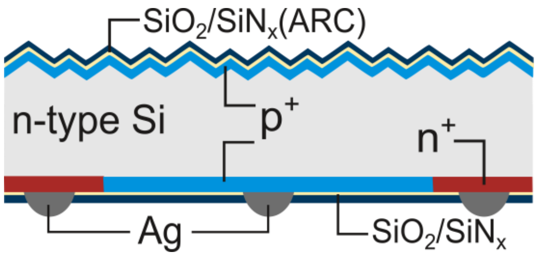
ZEBRA: key features

ZEBRA (IBC) bifacial low cost cell concept by ISC Konstanz



Photograph of the front and back sides (mirrored)

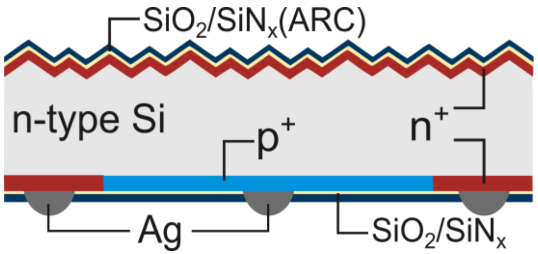
Two generations of process development:



Gen1 ZEBRA:

Front Floating Emitter (FFE)

Eta (best) ≈ 22.3%



Gen2 ZEBRA:

Front Surface Field (FSF)

Improved diff. / passivation

Improved metallization

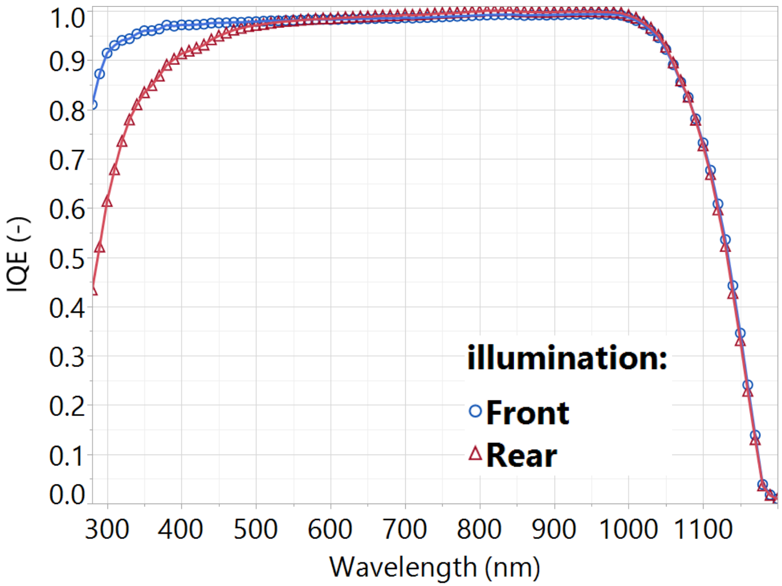
Eta > 23% (iVoc ≈ 715 mV)

ZEBRA: cell results

International Solar Energy Research Center Konstanz

Best cell parameters and bifaciality factor (BF) of Gen2 ZEBRA

Jsc (mA/cm²)	FF (%)	Voc (mV)	eta (%)	chuck
41.4	80.9	691.6	**23.2**	black
41.6	80.8	692.3	**23.3**	Reflective (white)



Key details and results:

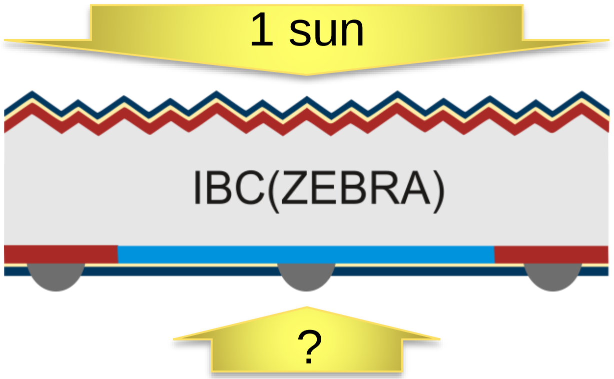
- » **high Voc (up to 696 mV)**
- » obtained on M2 (4 Ωcm) Cz wafers with ≈2 ms bulk lifetime)
- » **4 BBs** layout (per polarity)
- » **≈28%** rear total area shading (metal + isolation)

Cell BF (eta_{rear}/eta_{front})

≈ **67%**

Further improvements

International Solar Energy Research Center Konstanz



Cell bifaciality *versus* front side performance:
Can both be optimized?

Quokka3 modelling of the experimental best cell:

- Material parameters (base resistivity, bulk lifetime)
- Metallization shading and layout (finger & BB width, no. of BBs)

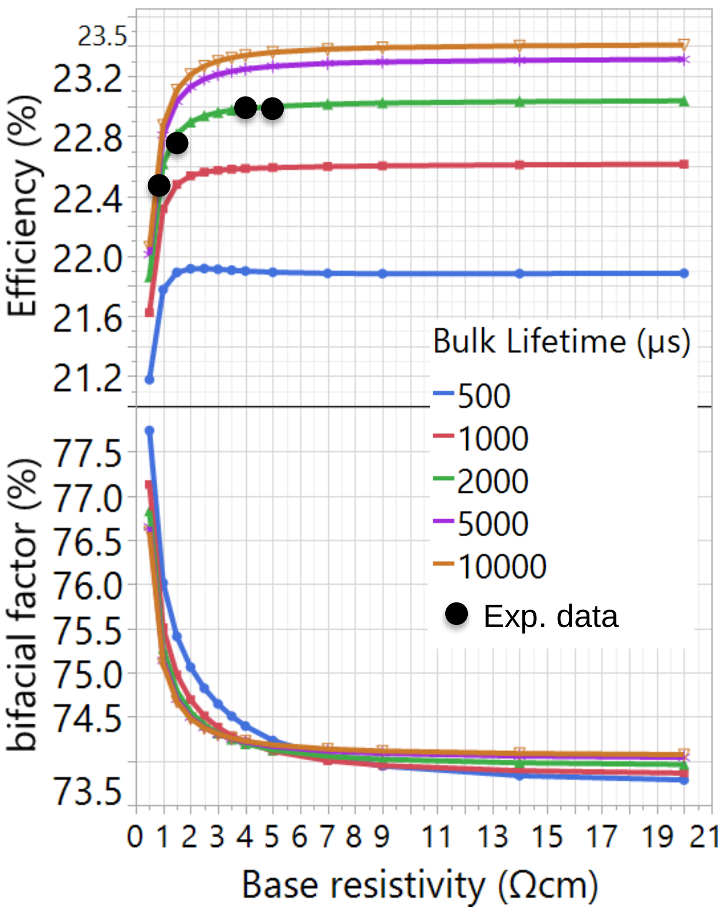
	Jsc (mA/cm²)	FF (%)	Voc (mV)	Eta (%)	BF (%)
Exp. data, front	41.4	80.9	691.6	**23.2**	67
Quokka3 model	41.3	81	691.4	23.1	74*

*The shading due to isolation pads not included in the simulation model

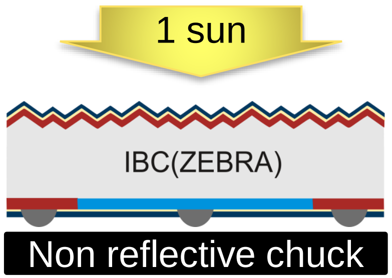
Quokka3 modelling results

International Solar Energy Research Center Konstanz

Effect of base resistivity and lifetime on BF and front side performance



Simulated setup:



Results:

» Resistivity ≤ 4 Ωcm,

⇒ eta ↑, BF ↓

» Resistivity > 4 Ωcm,

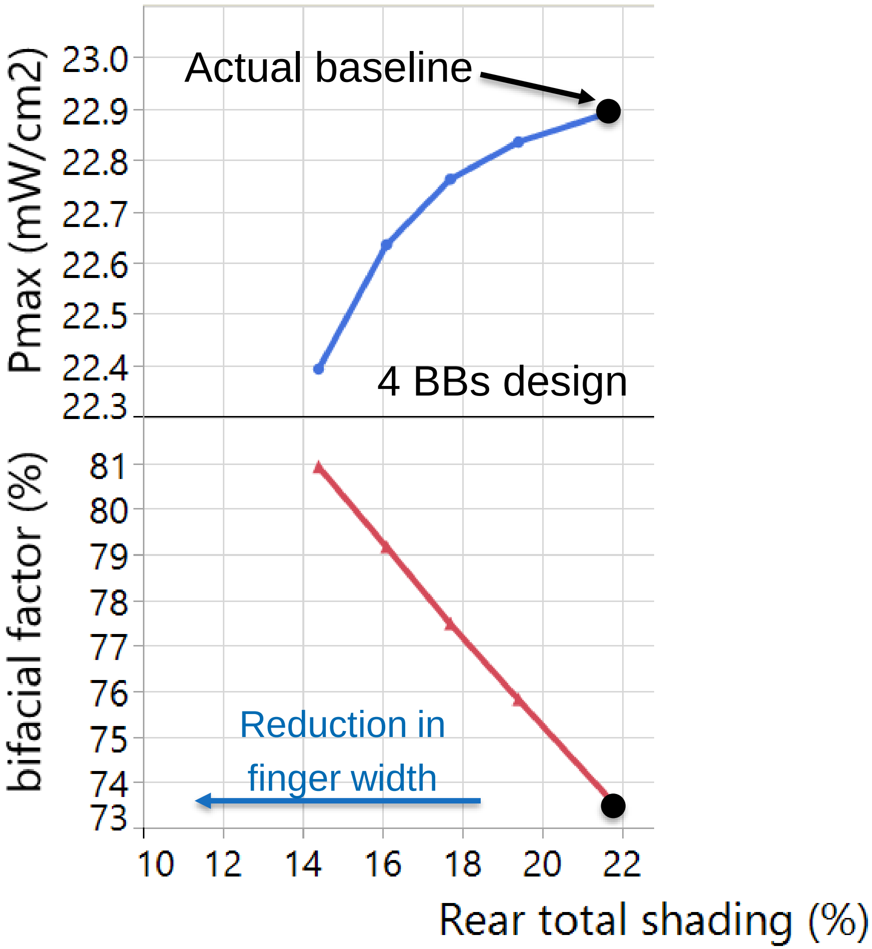
⇒ eta and BF ≈ constant

» Lifetime ↑ ⇒ eta ↑, BF ≈ constant

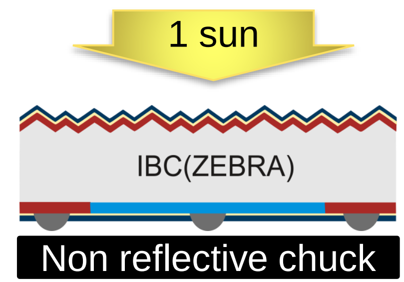
Quokka3 modelling results

International Solar Energy Research Center Konstanz

Effect of metallization shading on BF and cell power density (P_{max})



Simulated setup:

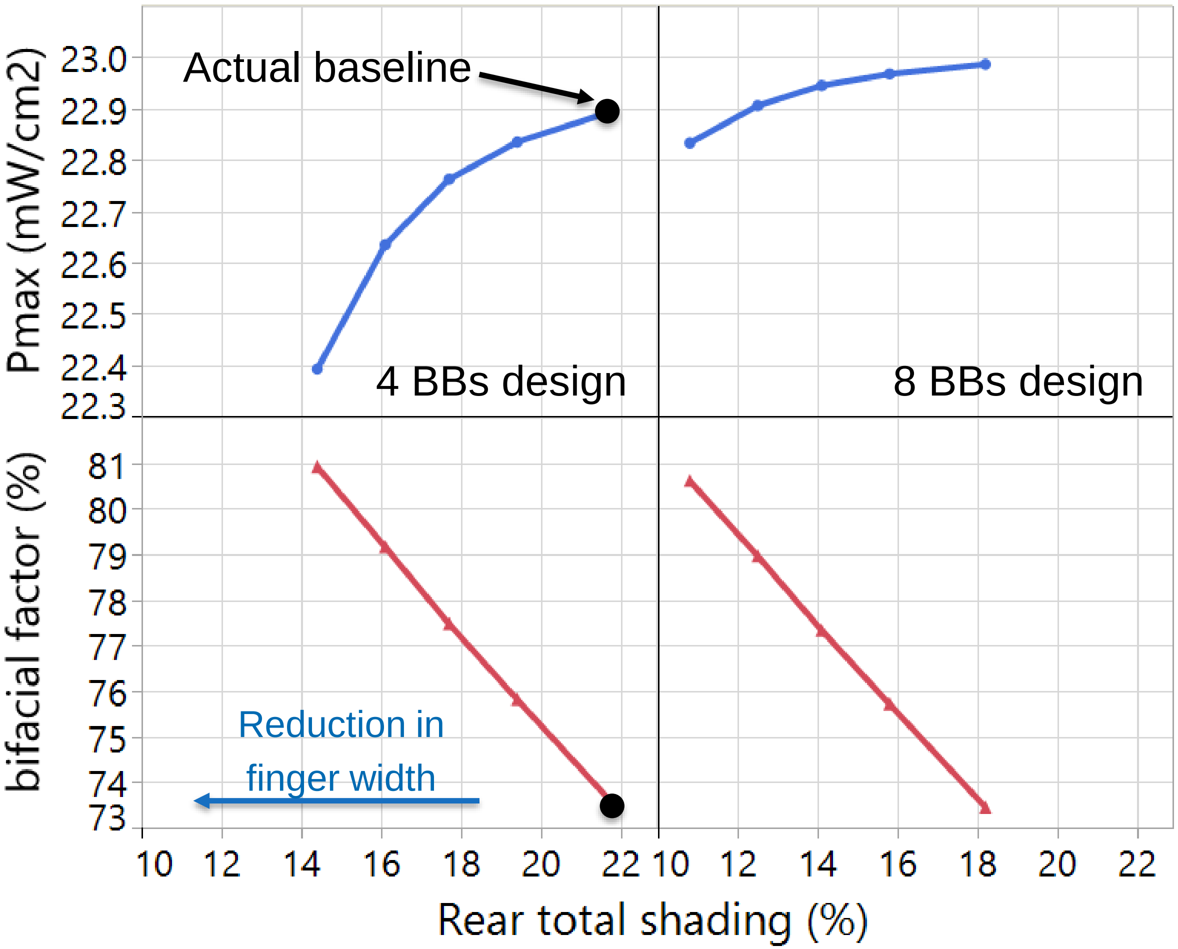


Results:

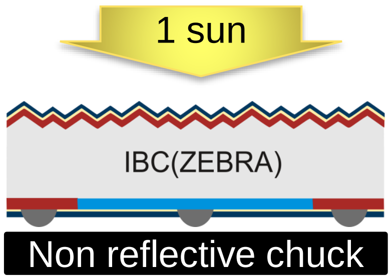
» 4 BBs ⇒ high power loss if reducing metal fraction

Quokka3 modelling results

Effect of metallization shading on BF and cell power density (P_{max})



Simulated setup:

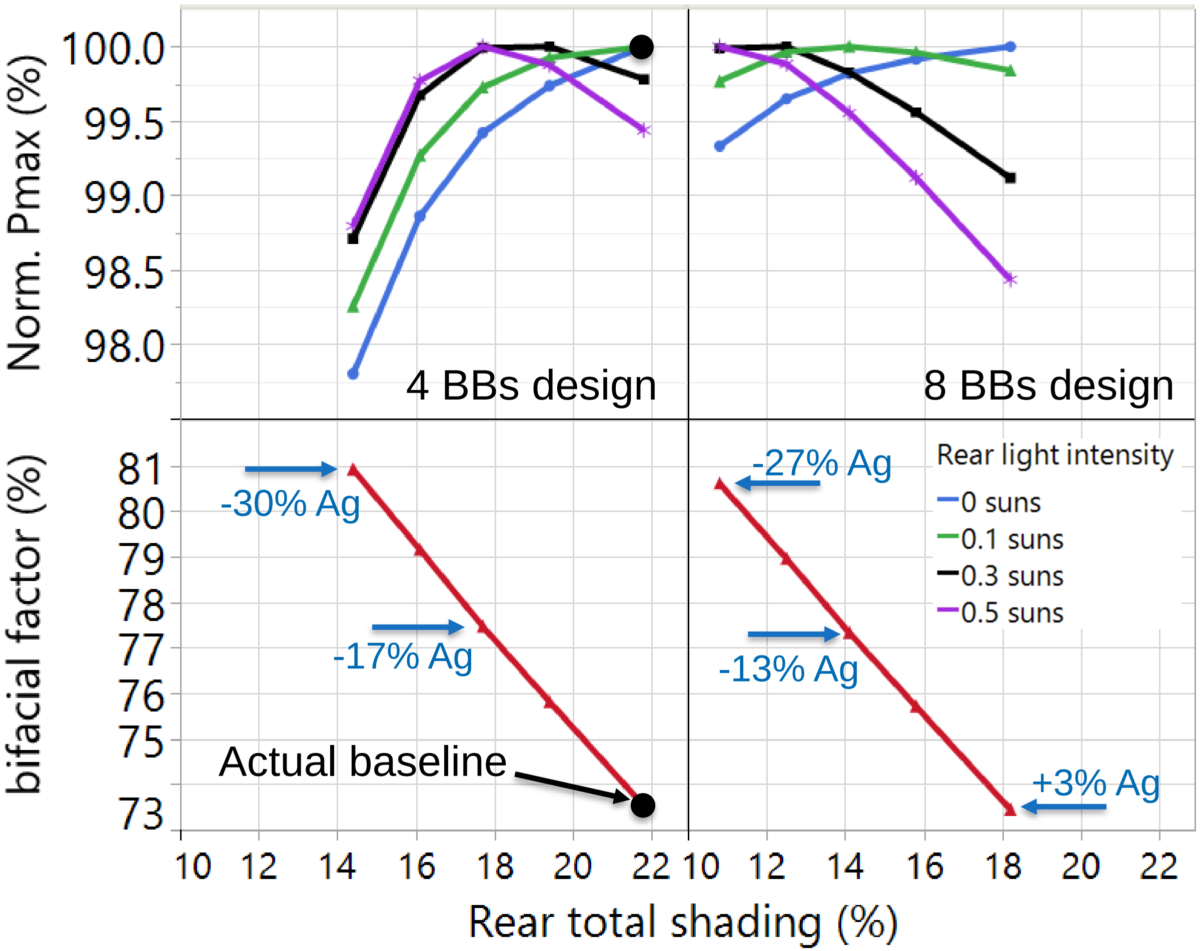


Results:

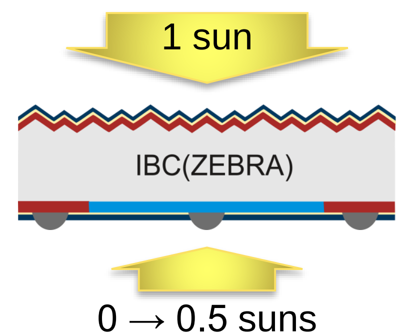
- 4 BBs ⇒ high power loss if reducing metal fraction
- 8 BBs ⇒ reduced power loss but optimum P_{max} still at high metal fraction (lower BF)

Quokka3 modelling results

Effect of metallization shading on BF and cell power density (P_{max})



Simulated setup:

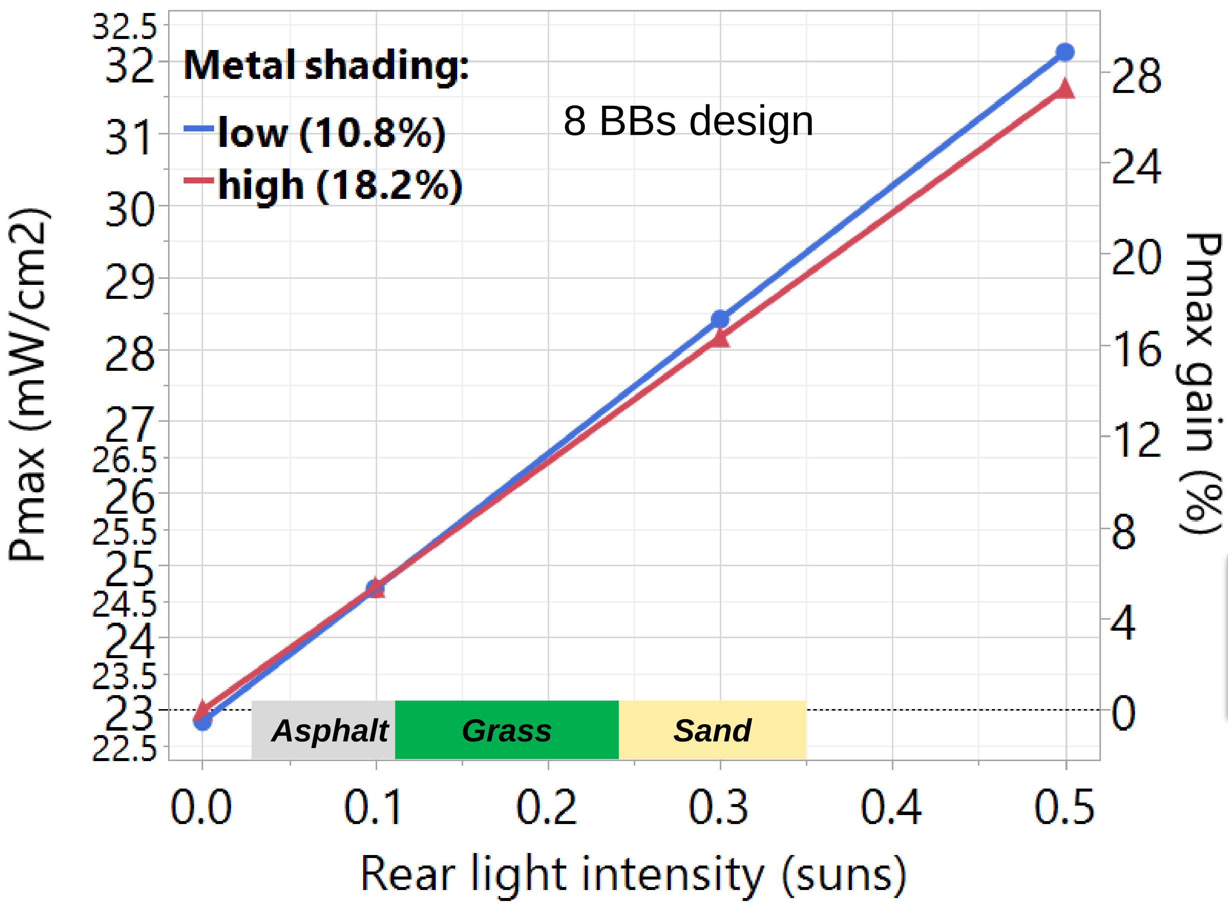


Results:

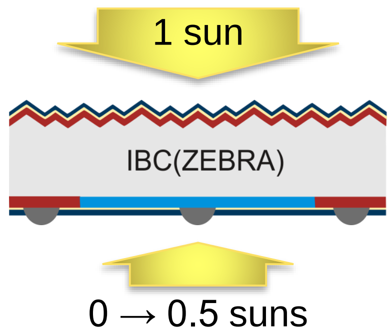
- » With additional rear illumination ⇒ optimum P_{max} → lower metal shading
- » Rear illumination ↑ ⇒ Ag paste consumption ↓

Quokka3 modelling results

Effect of rear side light intensity on cell power density



Simulated setup:



great potential for LCOE reduction!

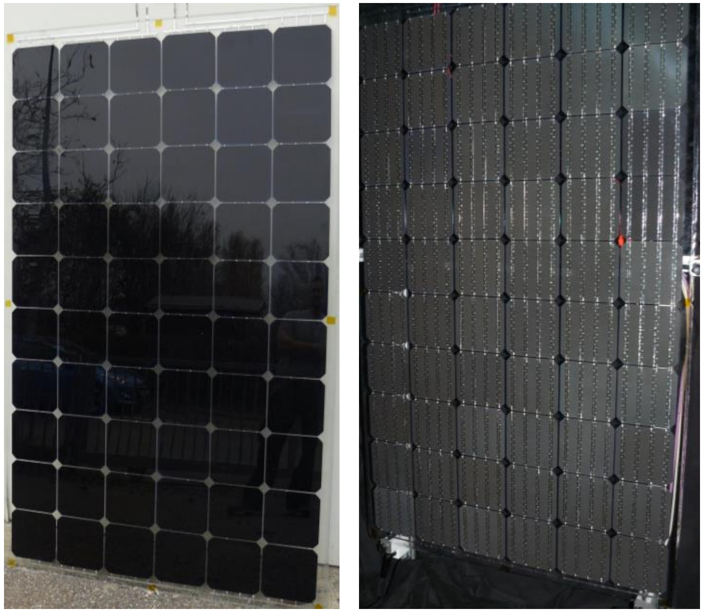
ZEBRA: module concept

International Solar Energy Research Center Konstanz

ZEBRA bifacial module concept

Key features:

- **ZEBRA gen1** cells (60 full cells, M2 wafers)
- Glass / Glass
- 4 BBs design
- CTM ≤ 3%



Photograph of the front and back sides of the 60 cell bifacial ZEBRA gen1 module

Module IV parameters (ISE CalLab certified)

Isc (A)	FF (%)	Voc (V)	Pmpp (W)	Measured side
9.789	76.4	40.879	**305.8**	front
7.488	77.3	40.445	**234.1**	back

Module BF (P_{rear}/P_{front}) ≈ **77%**

ZEBRA: module concept

ZEBRA bifacial module concept in mass production (at SPIC)

Key features:

» **ZEBRA gen2** cells (144 half cells, M2 wafers)

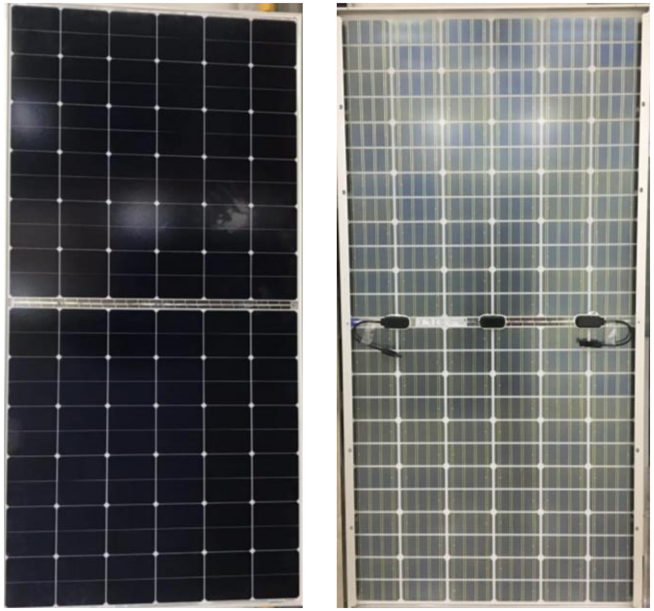
» Glass / Glass (or Glass / backsheet)

» White bifacial

» 4 (or more) BBs design

» CTM ≤ 2%

» IEC certification ongoing



Photograph of the front and back sides of the 144 half-cells bifacial ZEBRA gen2 module

Module IV parameters

Isc (A)	FF (%)	Voc (V)	Pmpp (W)	Pmpp (mW/cm²)	Measured side
10.139	79.8	49.25	**398.6**	20.5	front
7.175	79.2	48.56	**275.8**	14.2	back

Module BF

$(P_{rear}/P_{front}) \approx$ **70%**

Summary

International Solar Energy Research Center Konstanz

» ZEBRA – a cost effective bifacial IBC technology:
- ➢ efficiency ≥ 23.2% (best Voc ≈ 696 mV)
- ➢ BF_{cell} ≥ 67%, BF_{module} ≥ 70%

» Cell bifaciality *versus* front side efficiency:
- ➢ Bulk lifetime ↑ ⇒ eta ↑, BF ≈ constant
- ➢ Base resistivity ↑ ⇒ eta ↑, BF ↓
- ➢ Metal fraction ↑ ⇒ eta ↑, BF ↓

» With additional rear side illumination (0.1 → 0.5 suns):
- ➢ @ optimum P_{max} ⇒ metal shading ↓ (-25% Ag)
  ⇒ BF_{cell} > 80%

ZEBRA is the first bifacial IBC cell technology to enter mass production and be used (primarily) in bifacial modules!

Thank you for your attention!

Acknowledgement:

*project **FlexFab***
(0324194B)

Bundesministerium für Wirtschaft und Energie