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Bifacial solar cells - a brief overview

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Organizers: ISC International Solar Energy Research Center Konstanz, ines, ECN, zhaw School of Engineering

Sponsors: h.a.l.m., SunPreme, TEMPRESS, naturblau

Media partner: PV TECH, Photovoltaics, Photon

Bifacial solar cells

- Introduction

- Characteristics and physics
  - Bifaciality factor
  - Dependency on bulk, BSF, ….

- Bifacial solar cells
  - Past & Present
  - State of the art
  - Metallization challenges
  - New / innovative designs

Bifacial solar cells

- 1960: first description of bifacial cell by H. Mori
- 1977: first bifacial lab cells, n+pn+ / n+np+
- 1980: use of albedo realized

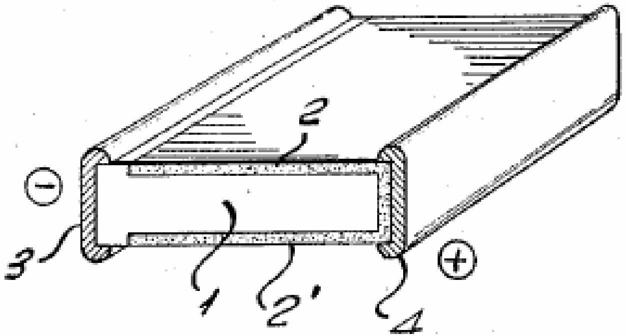


Figure 1. Double junction cell [1]. The numbers indicate 1: n-type silicon, 2 and 2': p-type emitter regions.

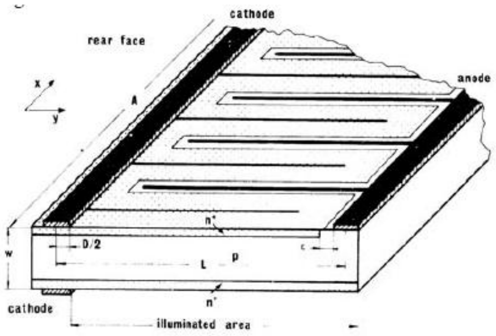


Figure 2. Double-junction solar cell, or Transcell [10].

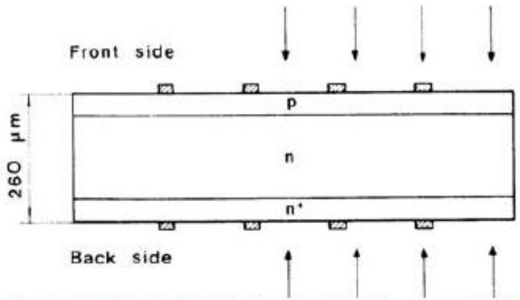
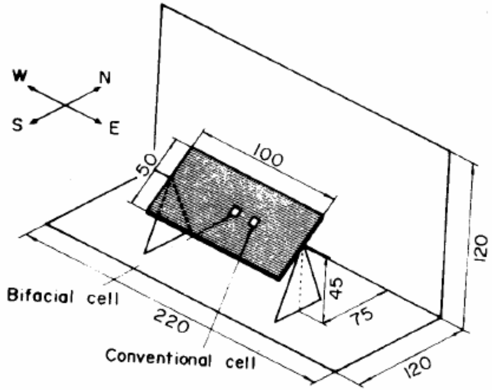


Figure 3. Bifacial Back Surface Field solar cell [26].



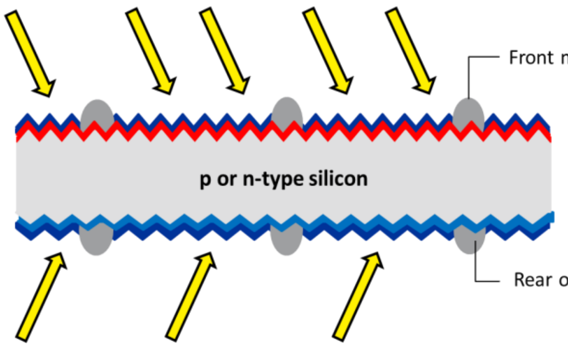
Ref: A. Cuevas, "early history of bifacial solar cells", 20th EUPVSEC 2005, Barcelona, Spain

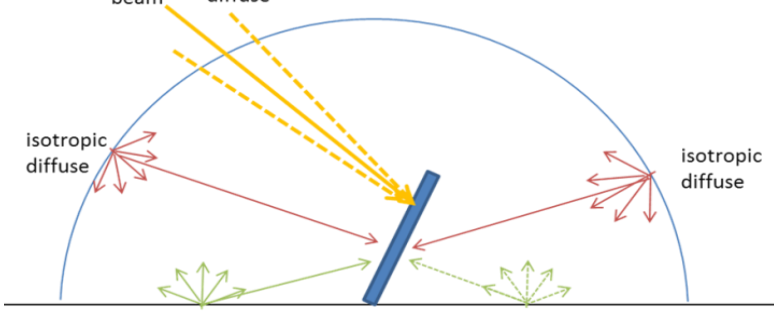
What is a bifacial solar cell?

- Simultaneous and efficient conversion of light that illuminates the solar cell from the **front side** as well as from the **rear side** into electricity

- A reflecting back sheet results in **increased monofacial module efficiency**

- A transparent rear **generates additional energy,** between 5% and 90% of the energy generated by only the front side.

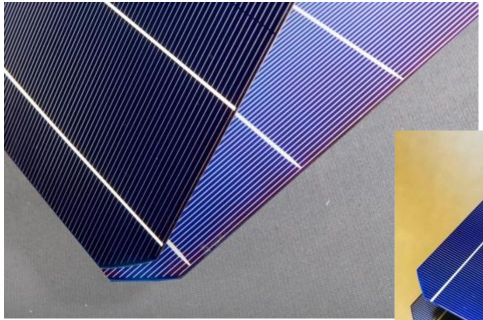


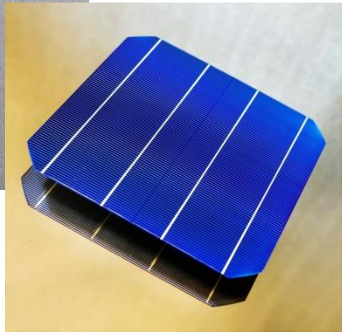


Characteristics bifacial solar cells: bifaciality factor φ

φ = ratio between front and rear response

$$\varphi_\eta = {}^{\eta_{rear}}/_{\eta_{front}}$$





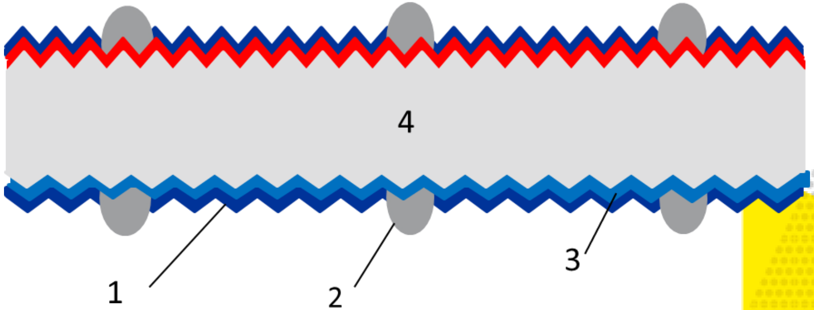
Usually φ <1

bifacial solar cells are typically not symmetrical

- Emitter/BSF
- Metal patterns optimized for front efficiency

Main parameters influencing φ:

1. Rear texture and ARC
2. Metal coverage on the rear side
3. Rear side (BSF) doping and passivation
4. Base resistivity and lifetime



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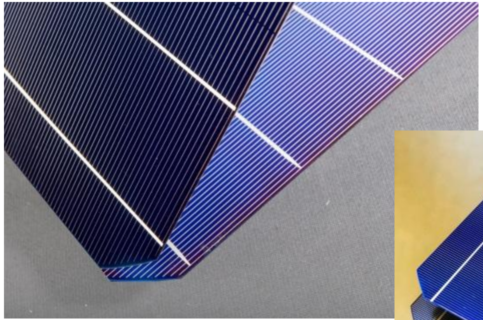

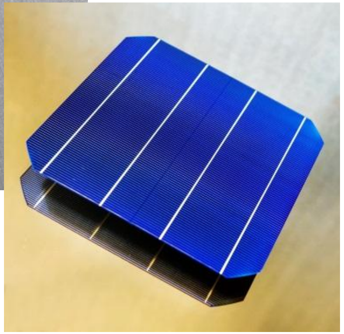

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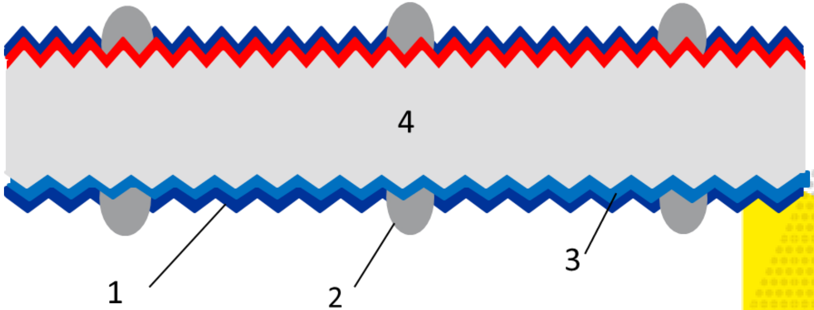
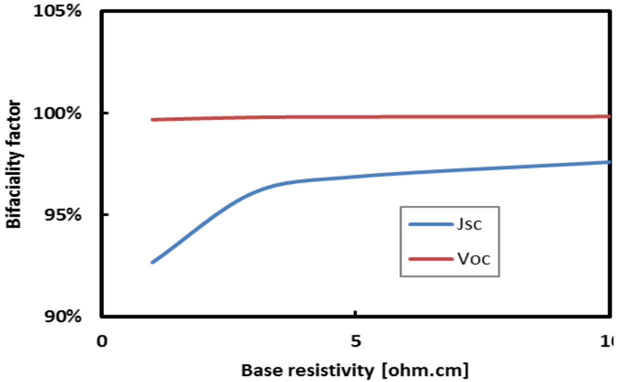
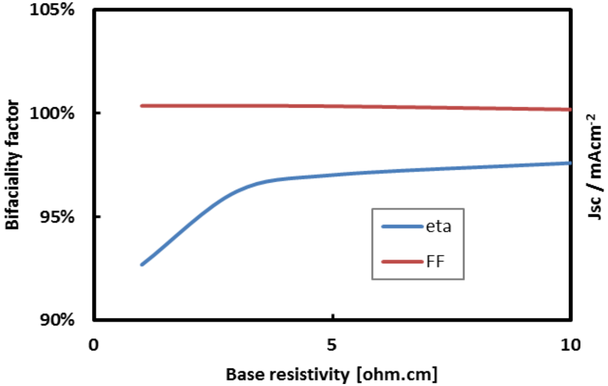


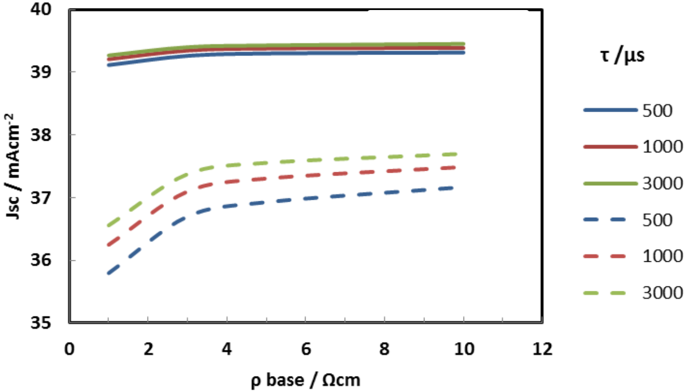
Effect of bulk resistivity and lifetime

Atlas simulations on n-Pert solar cells

- φ_{Voc}, φ_{FF}: (close to) unity
- $\varphi_{Jsc} = \varphi_{eta}$







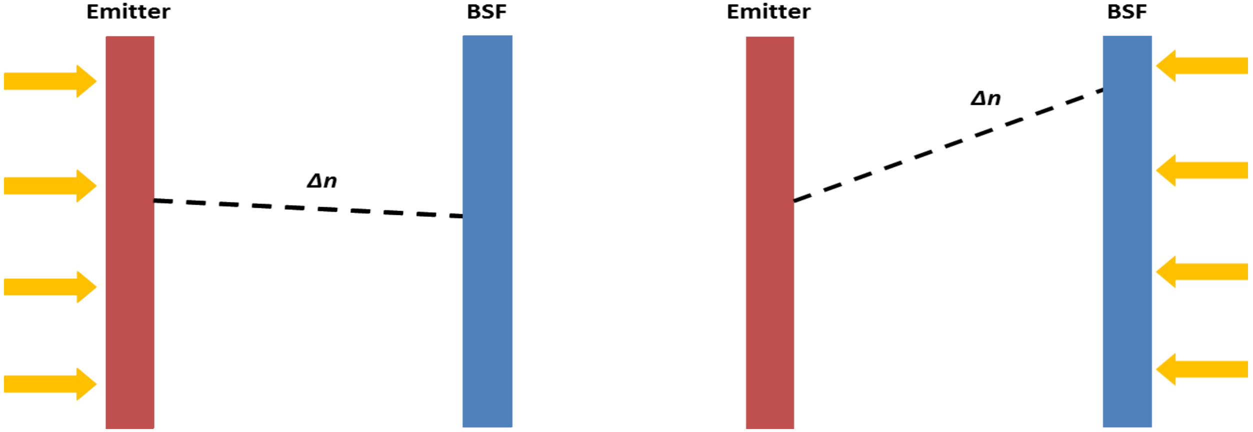
- J_{sc}: metal fraction + transport of carriers from illuminated side to other side
- High resistivity: lower N_D → less recombination → higher bifaciality
- Higher bulk lifetime → higher bifaciality

Bifaciality in n-PERT – dependency on BSF

BSF:

- Lateral conductivity → reduced metallization on rear
- Free carrier absorption
- Recombination (J_r)

$$J_{recomb} = J_{0,BSF} \frac{\Delta n \cdot (N_D + \Delta n)}{n_i^2}$$



Front illumination:

- Charge carrier transport to rear is field driven

Rear illumination:

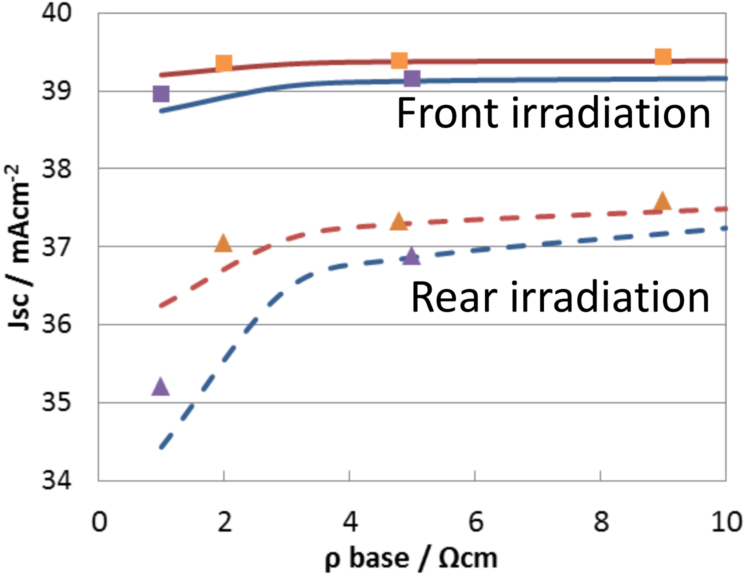
- Charge carrier transport to front is diffusion driven → high Δn builds up near BSF

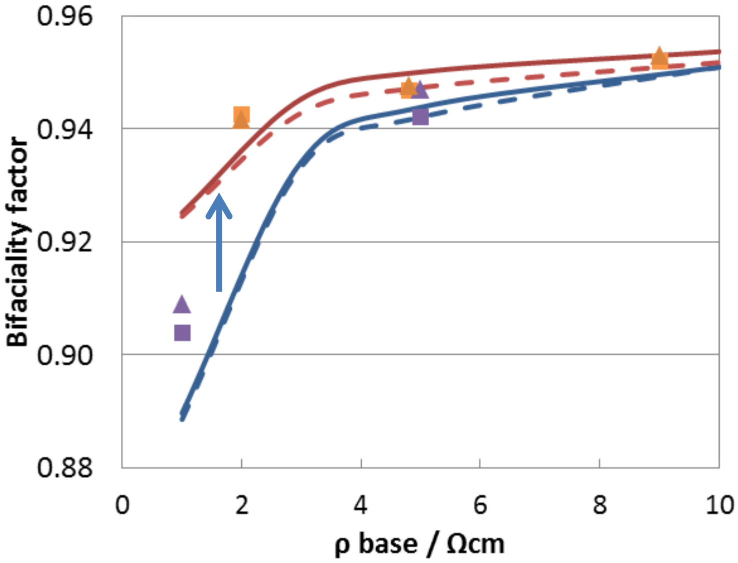
→ **Enhanced recombination**

Effect of BSF

Measurement data from n-Pert cells; Atlas simulations Gaby Janssen

Standard BSF
Improved BSF, identical metallization

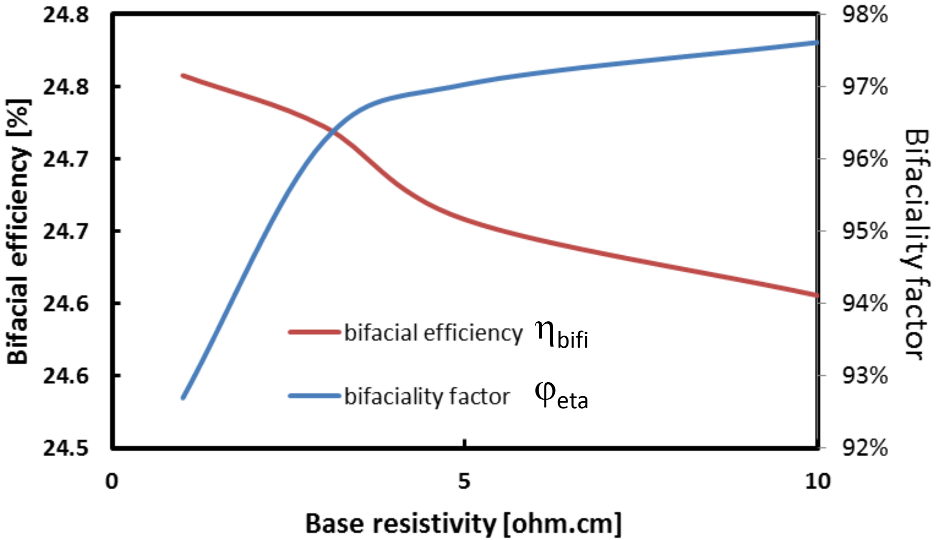




Improved J_{0BSF} (less Auger and surface recombination) → improved bifaciality

Trade off bifacial efficiency and bifaciality in n-PERT

- Low base ρ: improved lateral conductivity → increase in FF → High η_{bifi}
- High base ρ: reduced rear recombination → increase in φ_{eta}



Bifacial efficiency = η_{bifi20}, calculated for 1000 W/m² front and 200 W/m² rear irradiation

Cell design can be adapted for different resistivities

Cell design can be adapted for efficiency or bifaciality depending on module / application use

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Commercial bifacial solar cells

- 2000: Bifacial HIT cells from Sanyo in production

→ Symmetric metallization for thin wafers

- 2004 - 2008: large scale PV industry takes off….

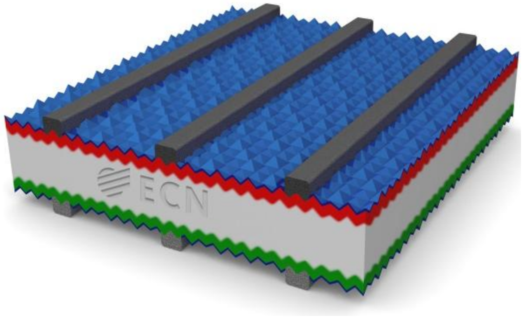
→ With monofacial cells and modules

- 2010: Yingli commercializes ECNs n-Pasha cells[1]

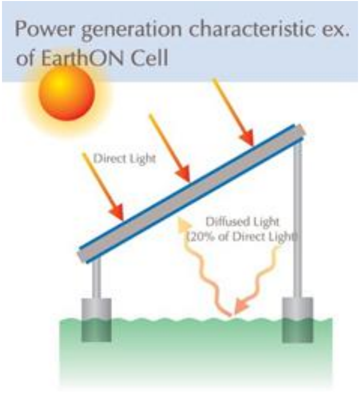
→ Applied in monofacial modules

- 2011: PVGS starts with EarthOn technology[2]

→ Applied in bifacial modules



PVG Solutions



1: A.R. Burgers, 26th EUPVSEC, Hamburg, Germany (2011)
2: S. Goda, 11th CSPV, Hangzhou, China (2015)

Bifacial cells predictions for the future

- First in appearance in ITRPV roadmap of 2017
- Bifacial cells become more and more prominent in the PV world
- Advanced cell concepts become industrialized – all can be made bifacial

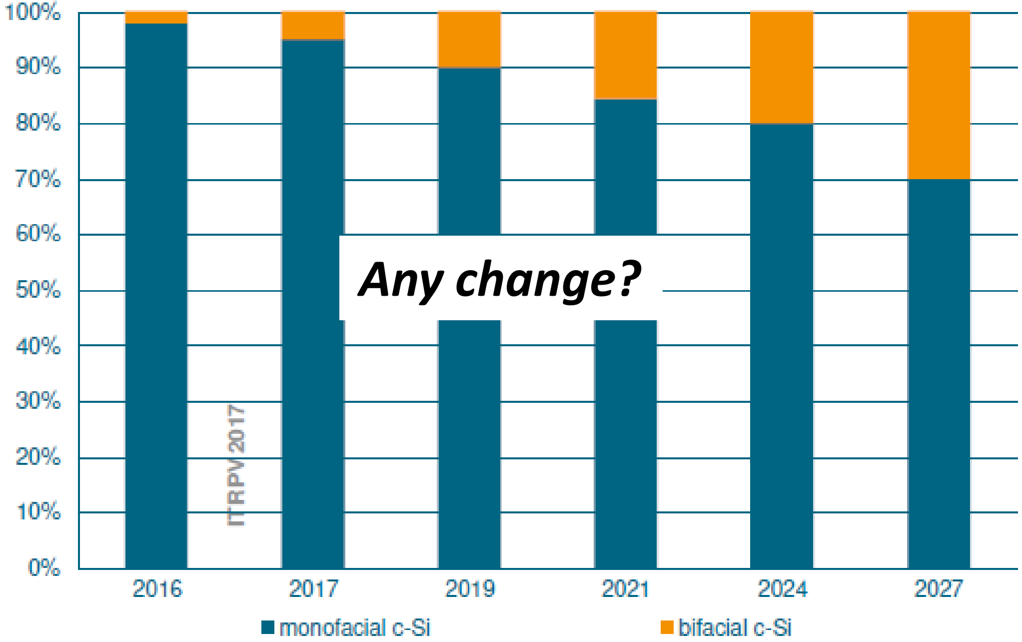
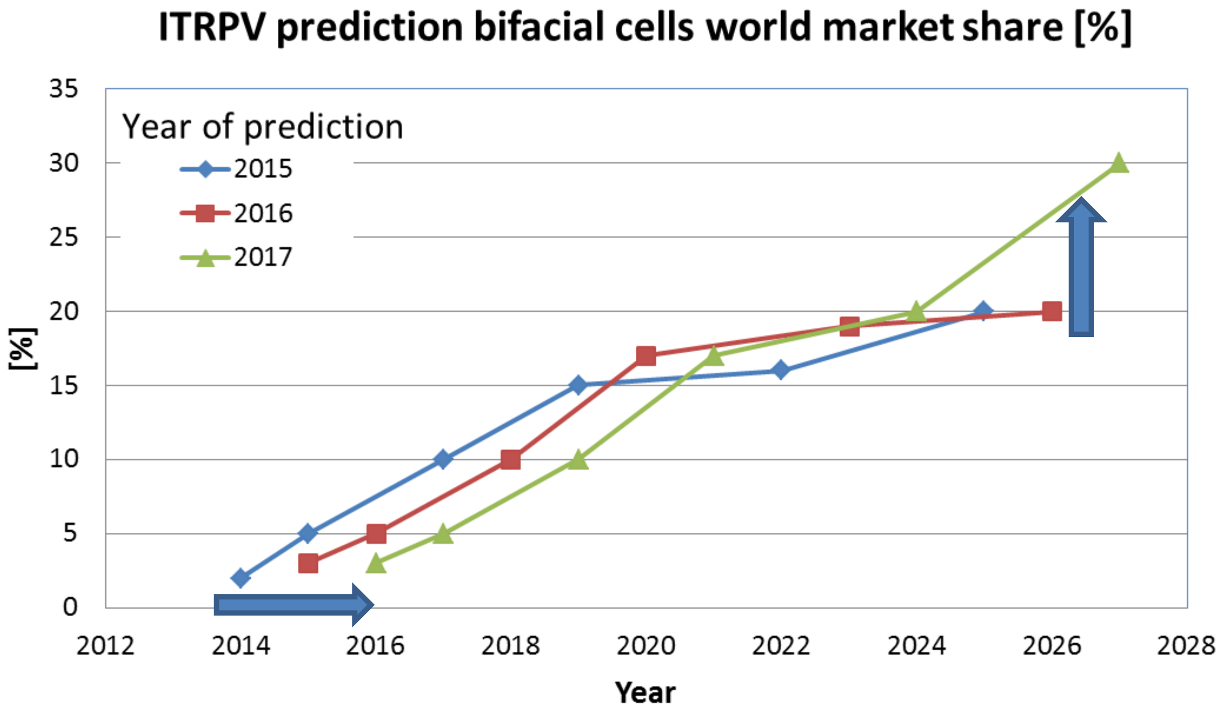


Fig. 29
Worldwide market shares for bifacial cell technology.

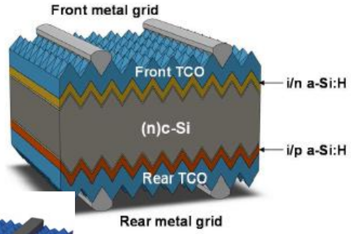
Bifacial cells predictions for the future

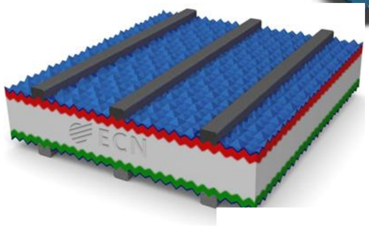
- Introduction slower then expected, but prediction becomes even more positive!

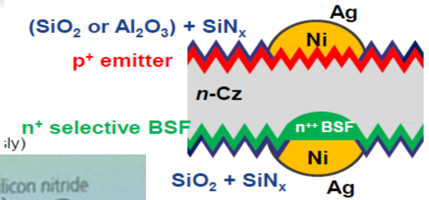


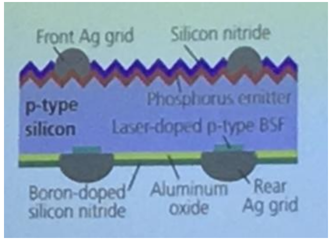
Different designs for bifacial cells

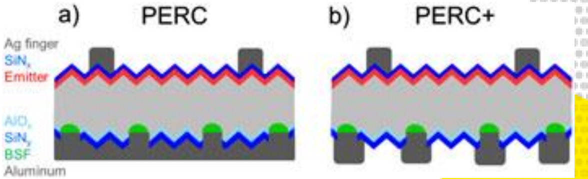
Selection of front and rear contacted bifacial cells			
technology	SP + Standard BB	TCO / plating No BB (grid touch)	bificiality
n-type			
HJ		>23.4% (MB)[1]	>95%
n-PERT	21% (ECN) 21.7% (Trina)	22.8 (imec)[2]	>95%
p-PERL	19.8% (ISE)[3]		>89%
p-PERT	20% (SolAround)[4]		>85%
p-PERC+	21.6% (ISFH)[4,5]		80%
p-type			











1: B. Strahm et al., 7th International Conference on Crystalline Silicon PV, Freiburg, Germany (2017)
2: R. Russell et al., 33th EUPVSEC, Amsterdam, NL (2017)
3: E. Lohmüller et al., 33th EUPVSEC, Amsterdam, NL (2017
4: S. Chunduri, M. Schmela, Bifacial Solar Module Technology, 2017 Edition, TaiyangNews
5: T. Dullweber et al., 31st EUPVSEC, Hamburg, Germany (2015)

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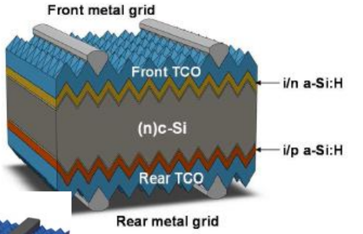

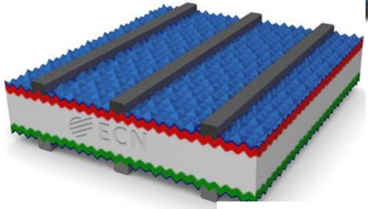

Selection of front and rear contacted bifacial cells

technology	SP + Standard BB	TCO / plating No BB (grid touch)	bificiality
Low T			
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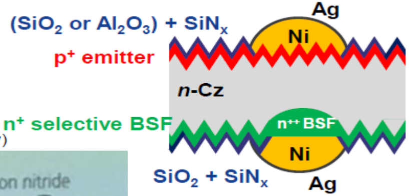
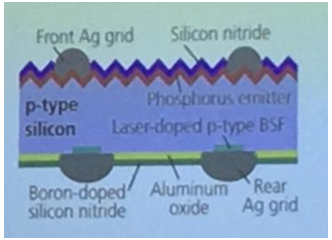
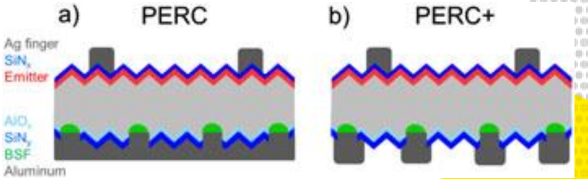
High T			







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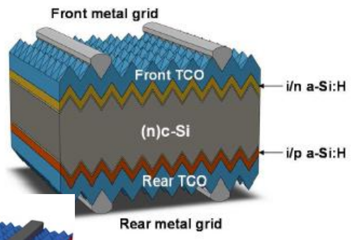

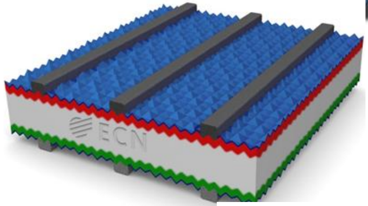

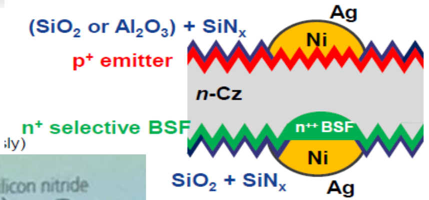

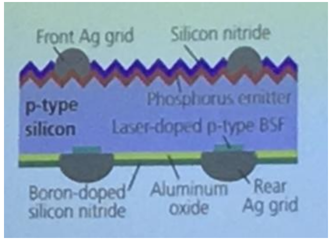

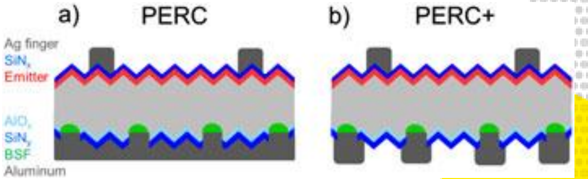

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Metallization: specifics, strengths and challenges

	HJ	PERT / PERL	PERC+
Specifics	TCO + Low T Ag paste or plating front and rear	Ag/Al paste front and Ag paste rear	Ag paste front Laser opening + Al paste rear

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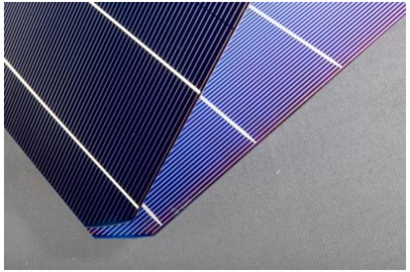
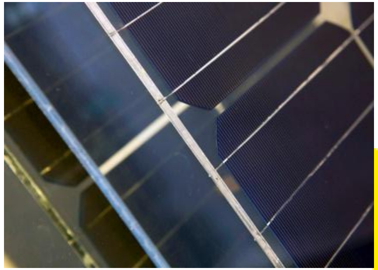
Challenges	**Low T metallization** **Need special module technology**	**Limited efficiency due to spiking of Ag/Al in emitter contacts**	**Limited bifaciality due to wide Al lines - lower ρ_{line}** **Alignment to laser**
Solutions	Smartwire (MB) or conductive adhesives	Selective emitters, reduce emitter contact area	Multi-Busbar Pattern recognition

Current commercial bifacial cells

Selection of PV companies working on different bifacial cell technologies[1]

technology	Eta	bifi						
HJ	22 – 23.5%	>95%	Sunpreme	3sun	Hanergy	Panasonic	Jinergy	
n-PERT	21 - 22%	>90%	Jolywood	Yingli	Adani	Linyang	Trina	LG
p-PERT	19 - 20%	>85%	SolAround	NSP	Shanxi Lu'An			
p-PERC+	21 - 22%	70%	SolarWorld	JA Solar	LONGi	Trina		

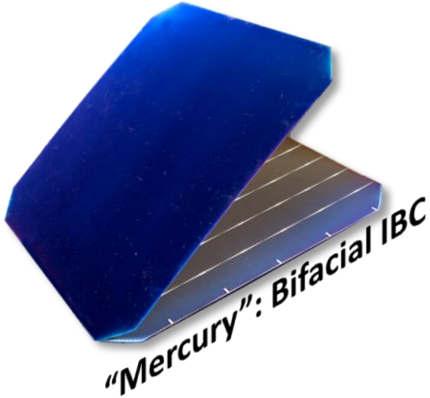


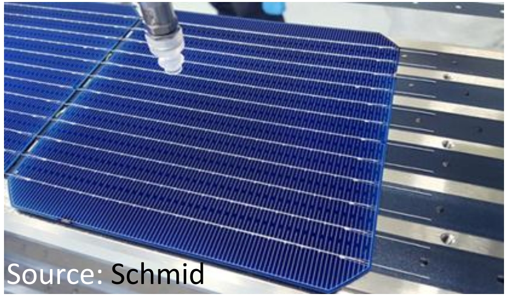


1: S. Chunduri, M. Schmela, Bifacial Solar Module Technology, 2017 Edition, TaiyangNews

Novel concepts: Bifacial back contact

- Several examples published
  - ECN's n-MWT[1]
  - ISC's Zebra IBC cell[2]
  - ECN's Mercury IBC cell[3]
- Bifaciality: 75% - 83%
- Interconnection – **so far R&D**:
  - standard soldering or gluing of ribbons
  - conductive backsheet
  - MultiWire or SmartWire

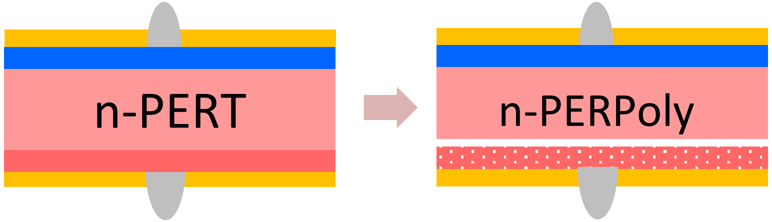




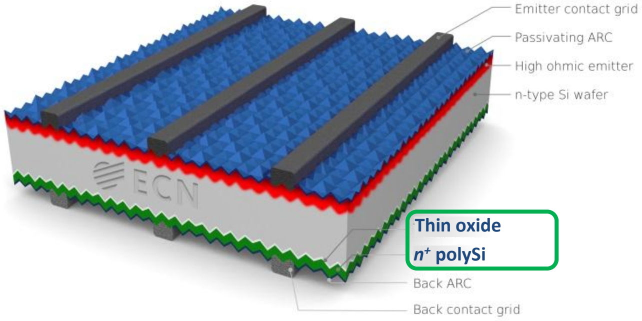
1: A. Gutjahr et al., 30th EUPVSEC, Amsterdam, NL (2014)
2: G. Galbiati et al., IEEE J. Photovolt., 3, pp. 560-563, (2013)
3. N. Guillevin et al., 33th EUPVSEC, Amsterdam, NL (2017)

Novel concepts: Industrial carrier selective contact cell

- n-PERT + n+poly-Si rear ➔ ECN's PERPoly cell
- Efficiency potential: up to 23%



Passivated **E**mitter and **R**ear **Poly** cell



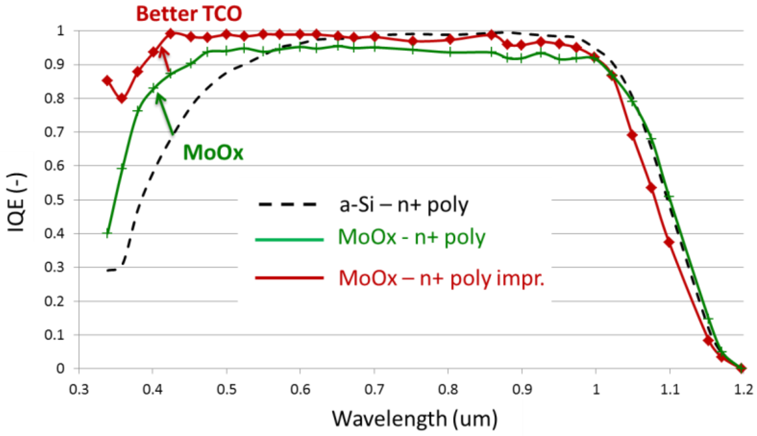
Properties

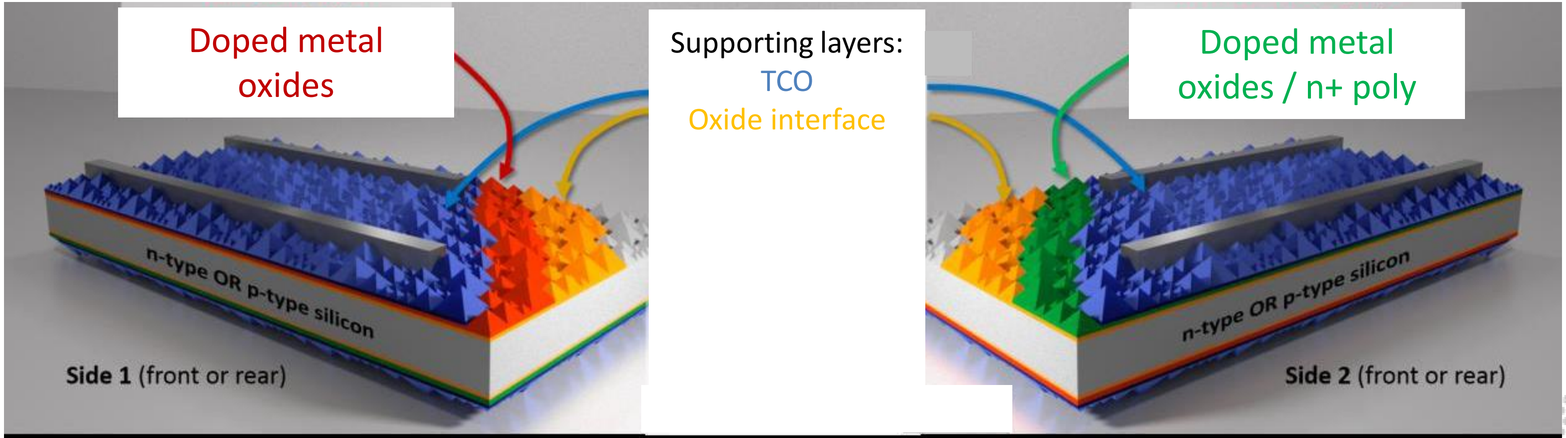
- 6 inch Cz material
- Print + fire through contacts
- Industrial, high throughput tools
- Bifacial → additional energy yield

Poly thickness	iV_{oc} (mV)	V_{oc} (mV)	J_{sc} (mA/cm^2)	*FF* (%)	η (%)	Bifaciality
80 nm	697	676	39.7	80.0	**21.5**	**86%**
150 nm	693	675	39.6	80.4	**21.5**	**81%**

Novel concepts: transparent metal oxide contacts

- Bifacial solar cell with transparent & highly selective contacts at both sides
  - Hole selective: MoO_x, WO_x
  - Electron selective: TiO_x, ZnO_x:Al
- First results at ECN: Moly-Poly cell with
  - Eta 18.1%, clear gain in blue response





KONSIL17
bifi PV workshop
Konstanz, Germany
October 25/26 2017

This workshop

- All bifacial cell concepts will be discussed:
  - PERC+, nPERT, pPERT and mcPERCT will be presented **in this session**
  - HJ (modules) will be presented in the **next session**
- Heterojunction, n-PERT and p-PERC+ are adopted by the industry
- Next generations bifacial cell concepts in R&D – mainly presented at SiPV, EUPVSEC
  - And the next bifi workshop?

Organizers: ISC International Solar Energy Research Center Konstanz, ines, ECN, zhaw School of Engineering

Sponsors: h.a.l.m., SUNPREME, TEMPRESS, naturblau

Media partner: PV TECH, Photovoltaics, Photon

- All advanced cell concepts can be made bifacial
- Bifacial solar cells are a great way to increase the module output
- Large playground to tune cell design for bifaciality, efficiency, ease of processing and costs

- Heterojunction, n-PERT and p-PERC+ are adopted by industry
- Next generations bifacial cell concepts in R&D
- **Bifacial cells are here to stay!**

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Thank you for your attention!

Thanks to the ECN bifacial team:
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