

Opportunity and Challenge:

>21% large-area *n*-type PERT bifacial solar cells in research and production

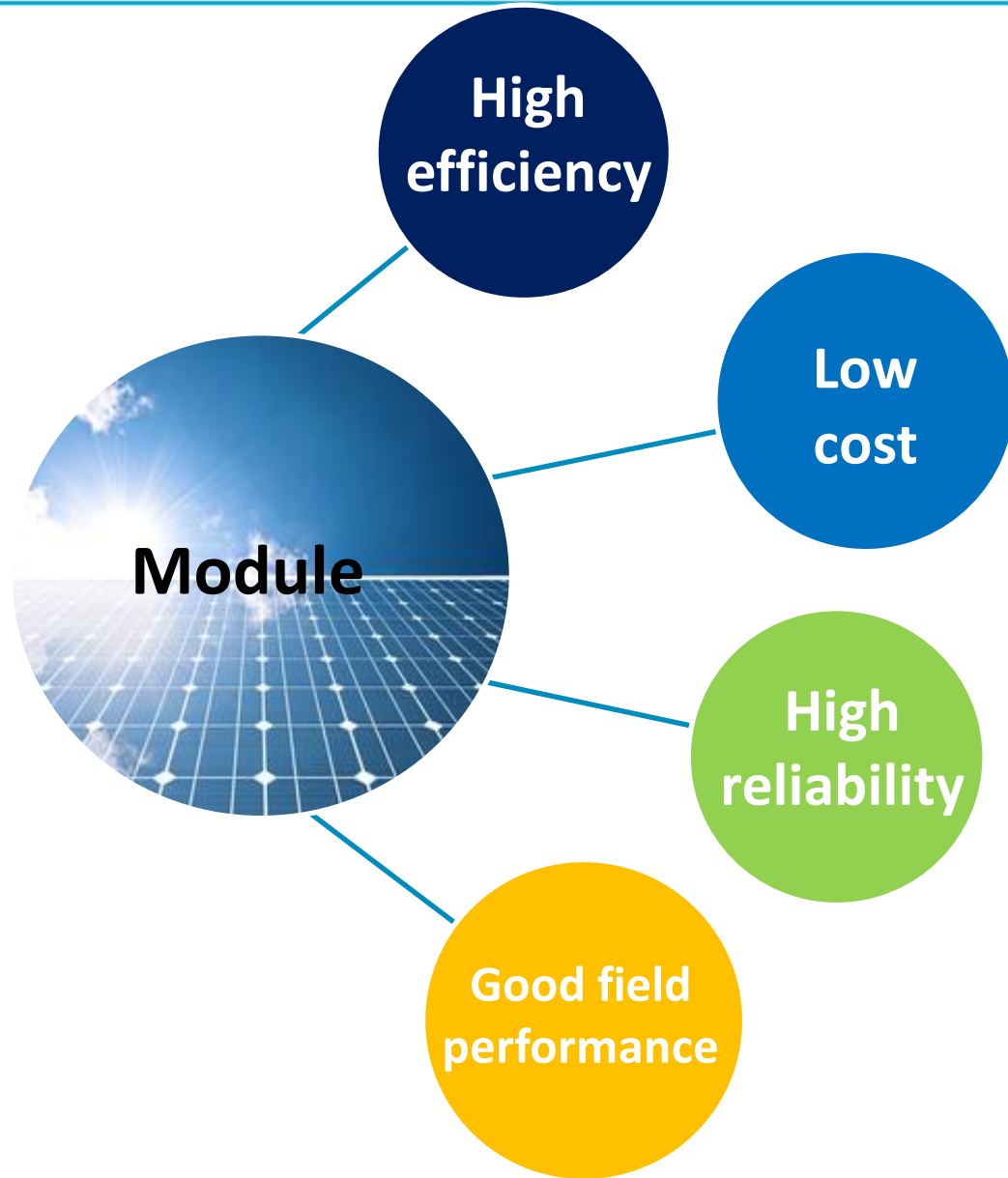
Yifeng Chen, Shengzhao Yuan,
Yanfeng Cui, Zigang Wang,
YunSheng, Chengfa Liu, Daming
Chen, Pietro P. Altermatt, Zhiqiang
Feng and Pierre J. Verlinden

Sep 29th, 2016



Key elements for a PV module

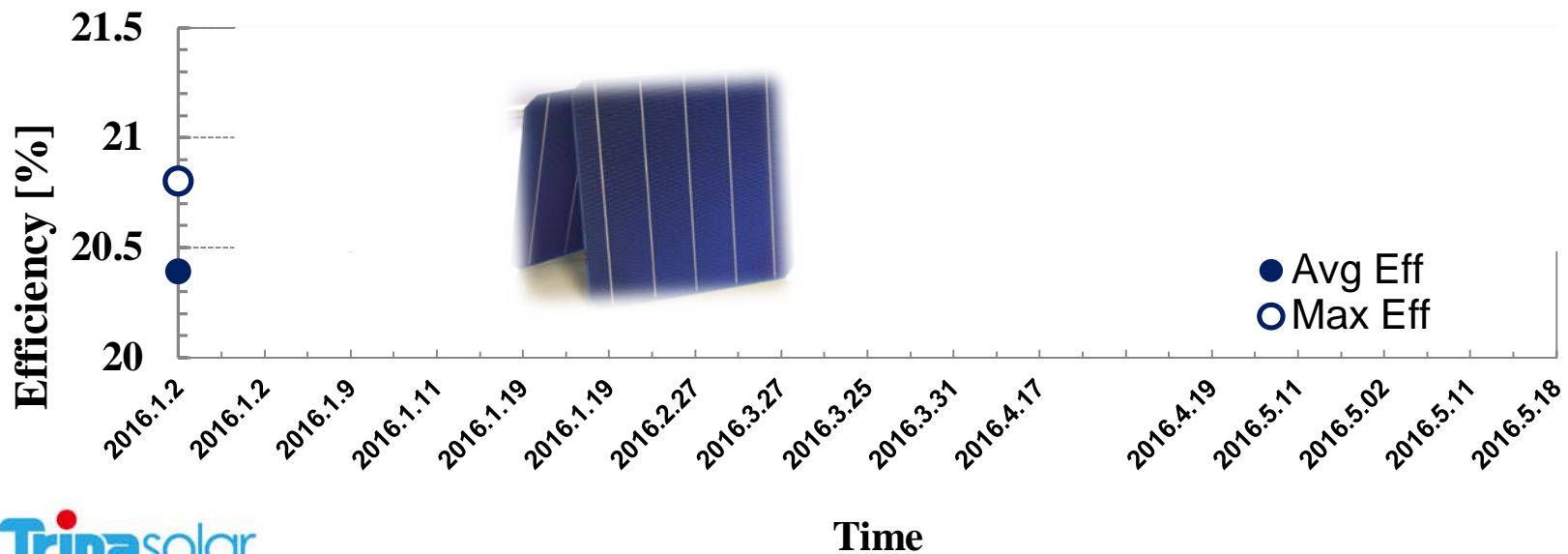
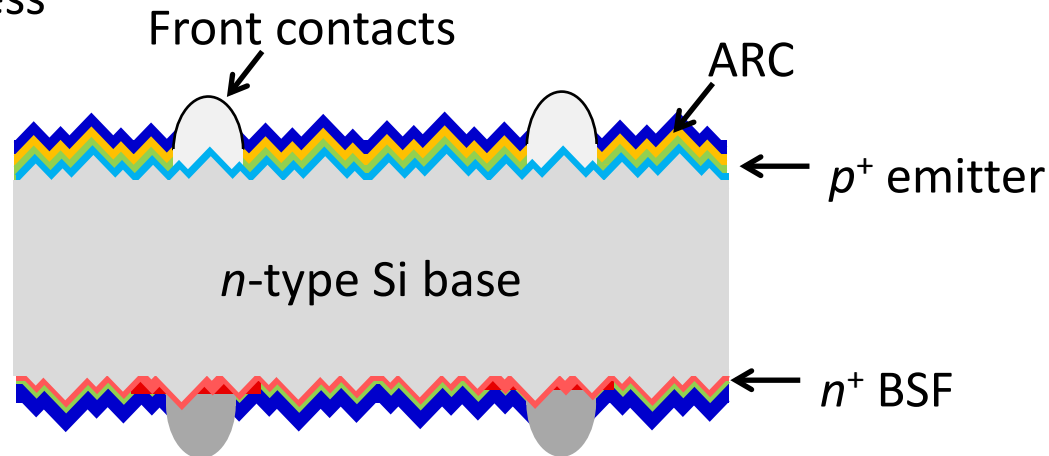
**Reducing the
Levelized Cost
of Electricity
(LCOE)**



First development of *n*-type bifacial in Lab

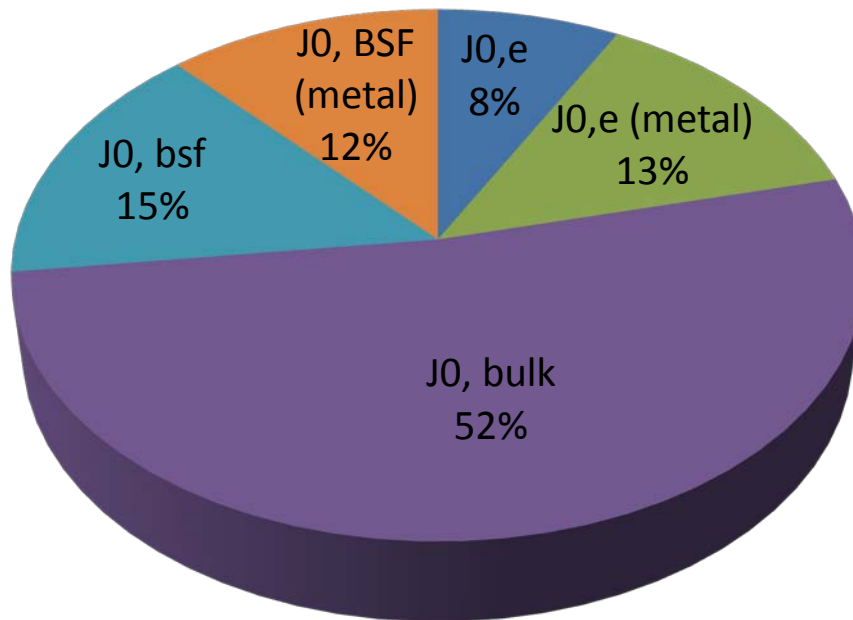
Industrial feasible tools and process for **stable** mass production:

- ✓ Tube boron diffusion
- ✓ Tube phosphorus diffusion
- ✓ PECVD double side passivation
- ✓ Front & Back screen printing



Power loss analysis

J_0 distribution of a 20.4% cell



Fabricate reference sample to extract J_0 in:

Emitter **No. 3**

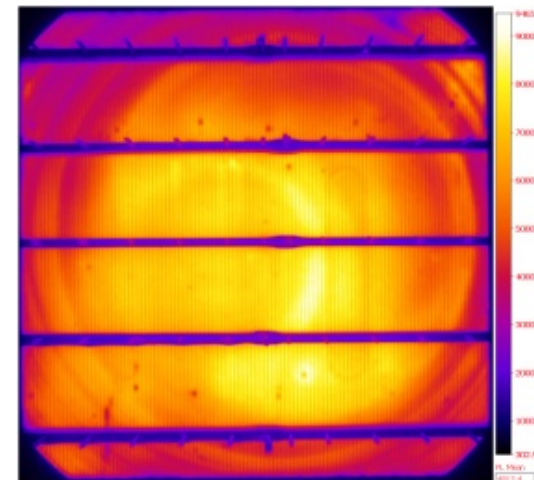
Auger, SRH, front surface (passivated), front contact

Base: **No. 1**

Auger, SRH

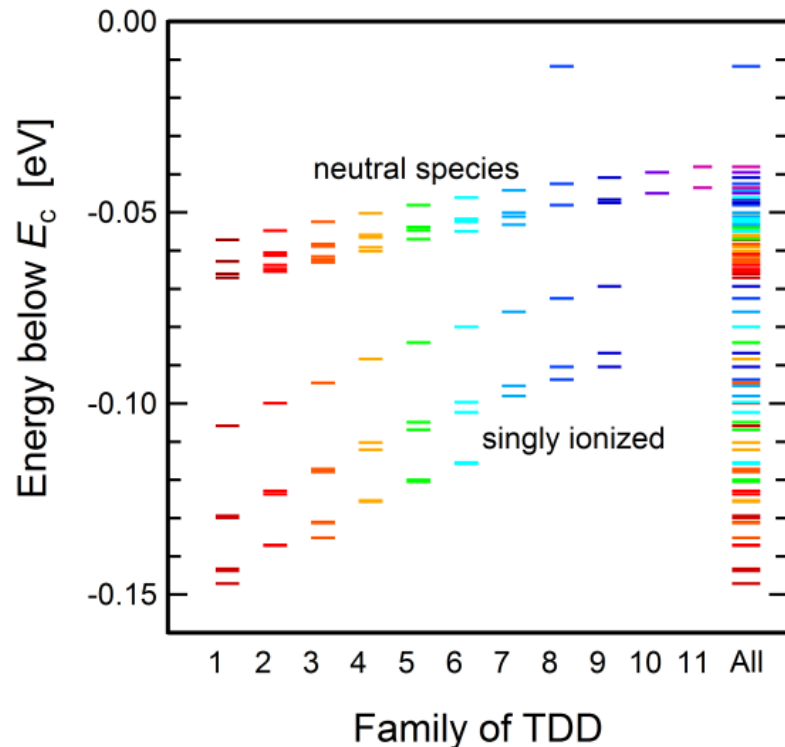
BSF: **No. 2**

Auger, SRH, rear surface (passivated), rear contact



Shallow defects in n-type material

n-type: lifetime may be influenced by shallow defects



- **Thermal double donors (TDD).**
Defect levels from 50 – 69 meV below the conduction band edge, E_c , (neutral states), from 114 – 156 meV for singly ionized (positively charged) states. [1,2]
- Sometimes, thermal donors can form **associated deep defect levels** by reacting with impurities [3,4]

[1] D. Wruck, P. Gaworzewski, Phys. Stat. Sol. (a) 56, 557 (1979).

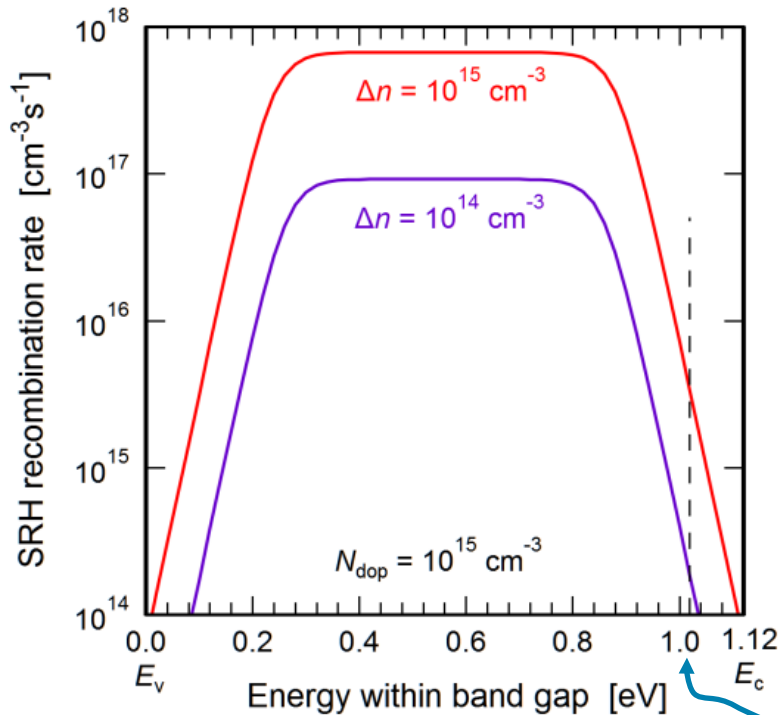
[2] A.R. Bean, R.C. Newman, J. Phys. Chem. Solids 33, 255 (1972).

[3] E. Simoen et al, J. Elchem. Soc. 150 , G520-G526 (2003).

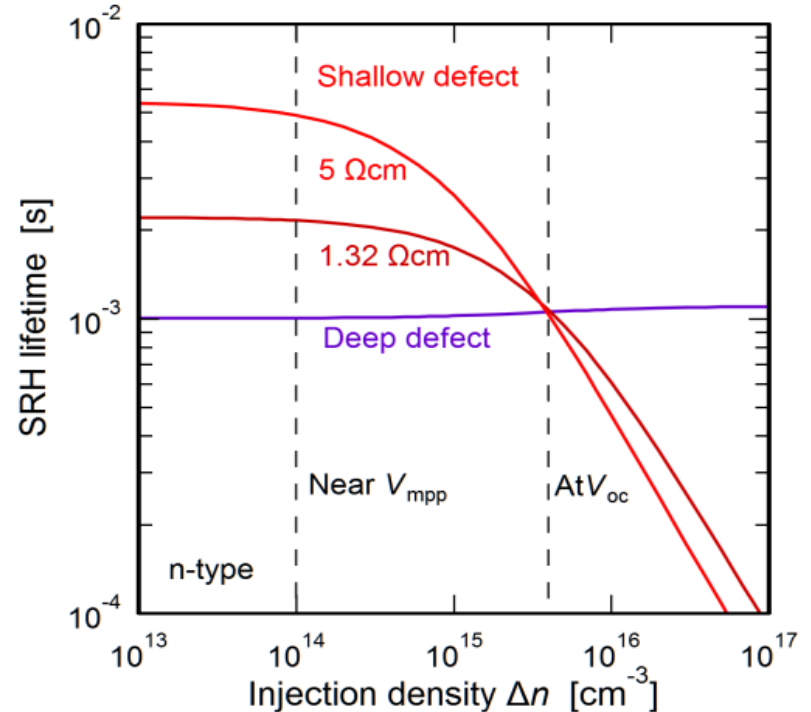
[4] M. Tomassini et al, J. Appl. Phys. 119, 084508 (2016).

Shallow defects in n-type material

n-type: lifetime may decrease with bias (with inj. level)



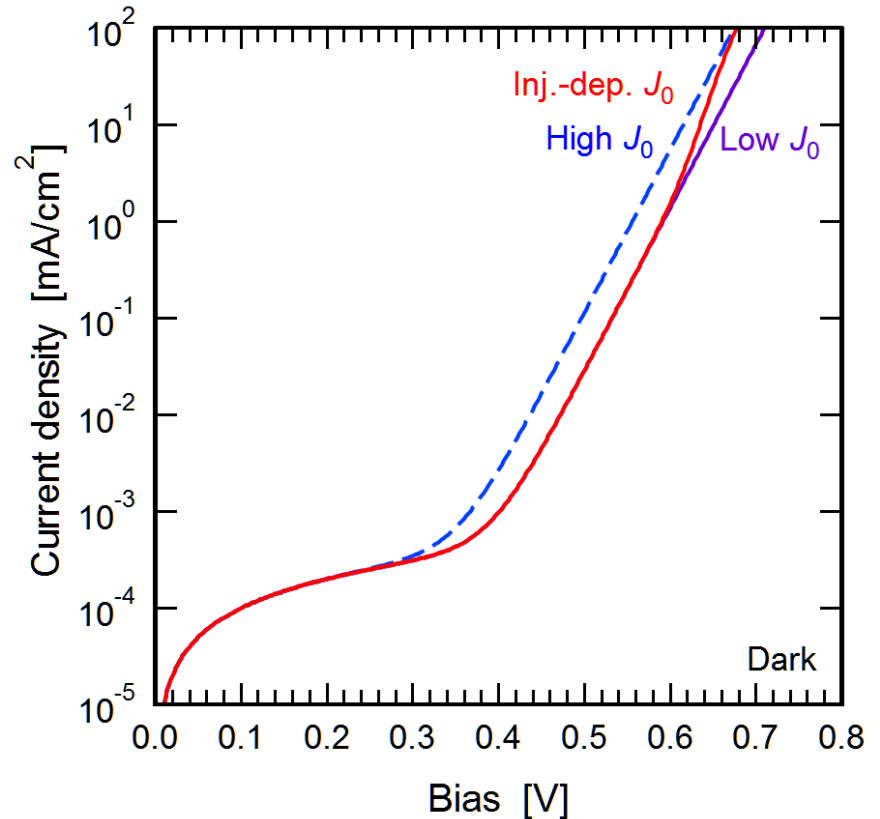
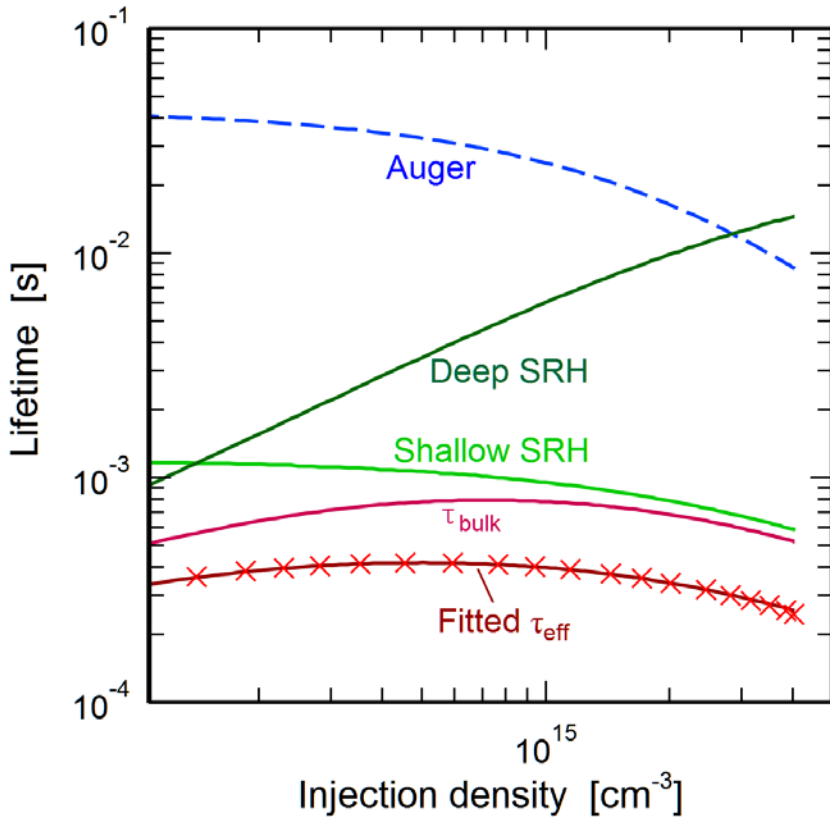
Higher injection Δn widens plateau, shallow defects become more recombination active



Difference in lifetime between V_{mpp} and V_{oc} is maximal at $E_d < 100 \text{ meV}$ and at low N_{dop} .

Mechanism of FF changes

n-type: lifetime **de**creases with bias \rightarrow **in**crease of FF

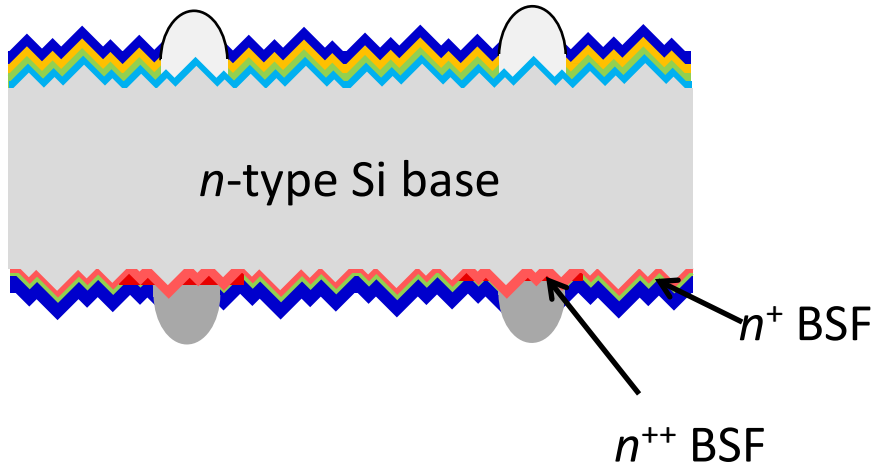


Higher voltage
Higher Δn (injection density)

$$FF = \frac{J_{mpp} V_{mpp}}{J_{sc} V_{oc}}$$

inj.-dep.
lifetime
increases
FF

Efficiency improvements roadmap in Lab



Improvements to avg. eff. **21.3%** by:

Base:

→ Improving bulk lifetime

Emitter:

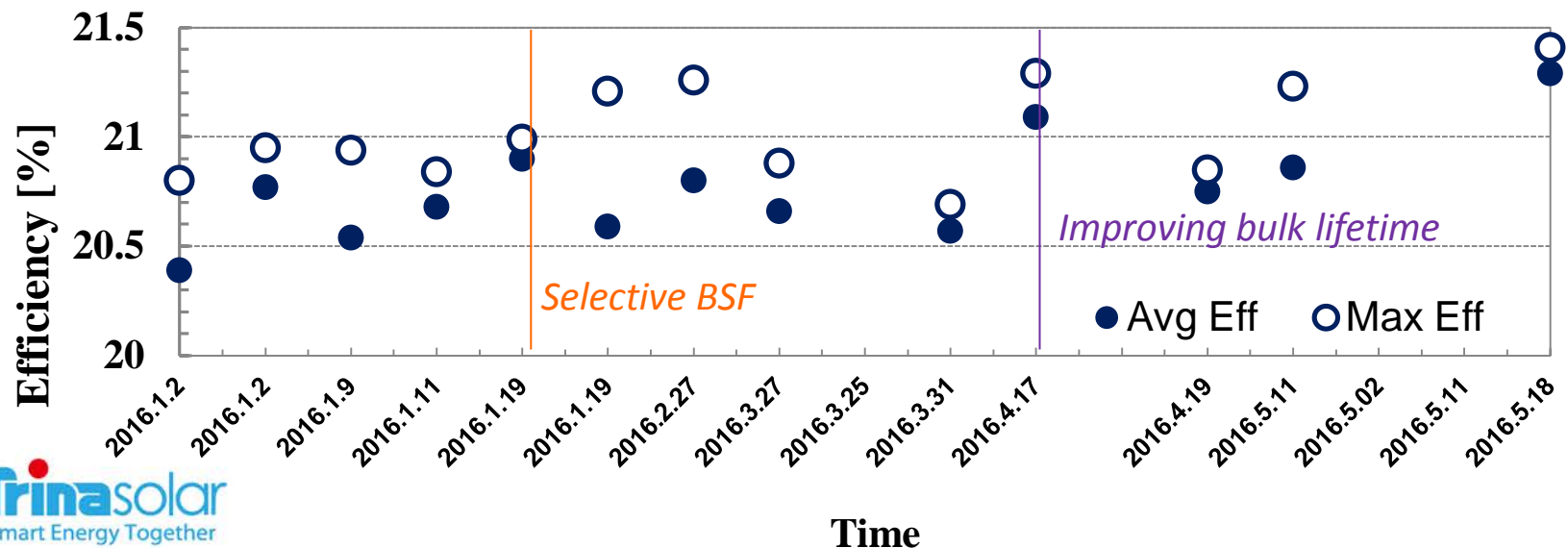
→ Optimization of surface passivation

→ Improving metallization

→ Boron diffusion thermal budget

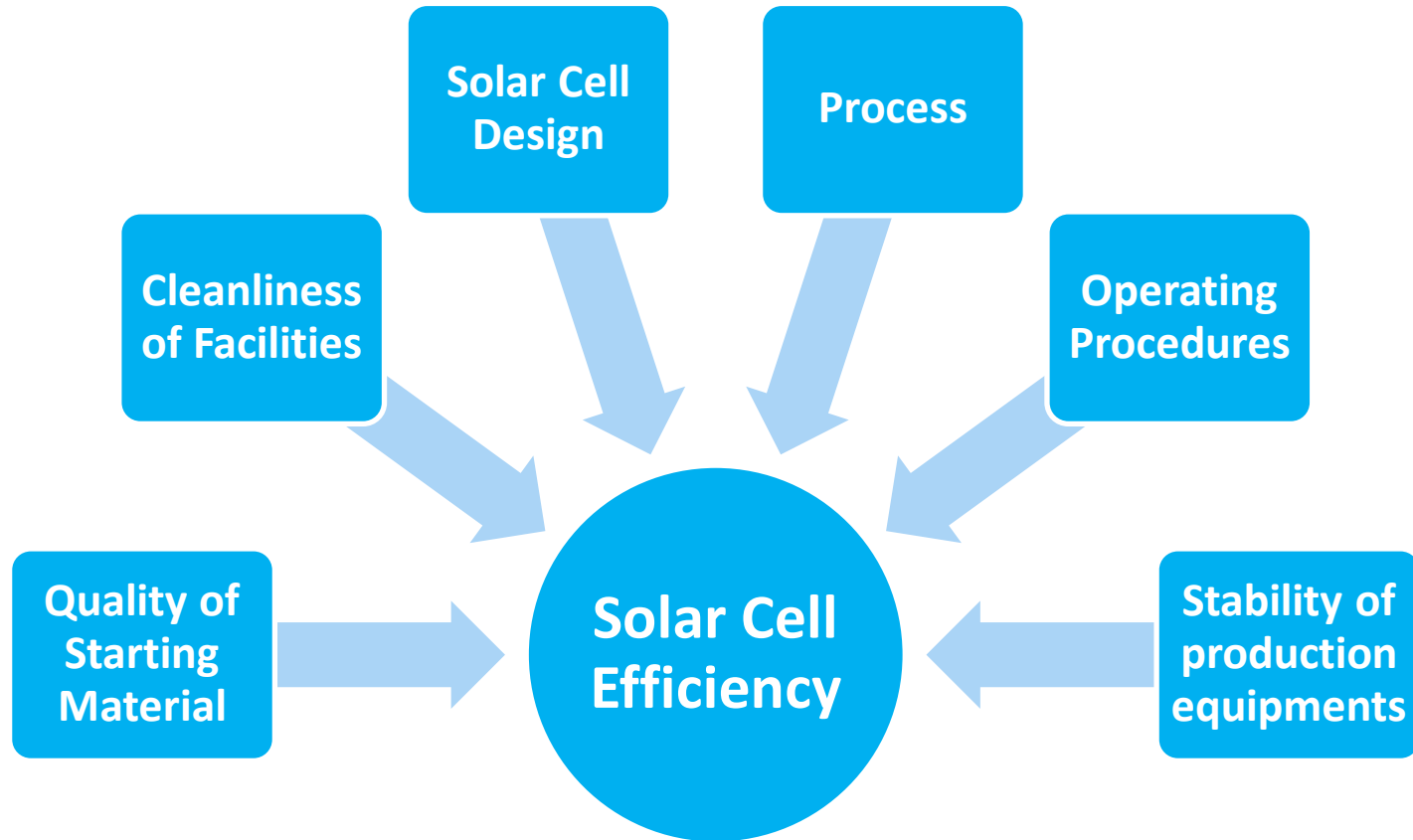
BSF:

→ Selective BSF



Demonstration of >21% efficiency in **pilot line**

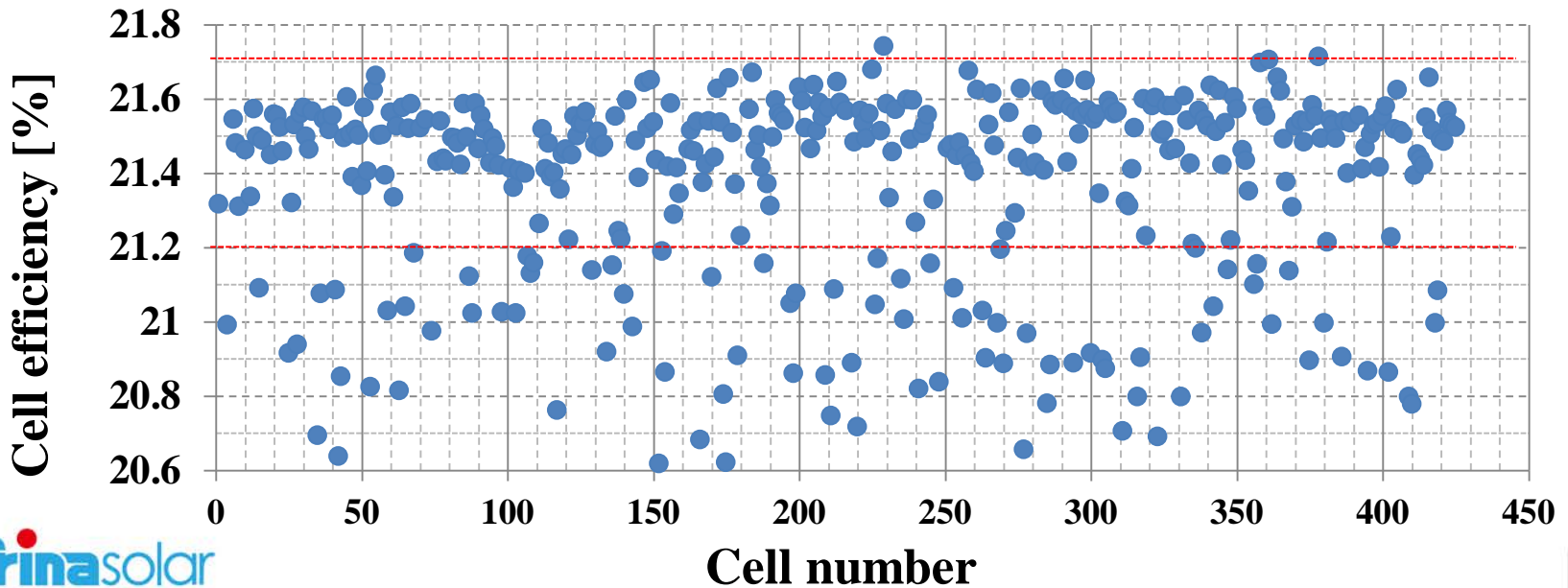
- Solar Cell design is not the only thing to improve



Demonstration of >21% efficiency in pilot line

- We started pilot line from June 2016
- Latest batch run in a pilot line in “Golden Line”, rear side efficiency 20.4-20.8%

	<i>Eff.</i> [%]	J_{sc} [mA/cm ²]	V_{oc} [mV]	<i>FF</i> [%]
Average	21.23	39.48	668.4	80.74
Median	21.44	39.60	671.4	80.89
Best	21.74	39.81	673.1	81.49



First batch of double glass modules & reliability

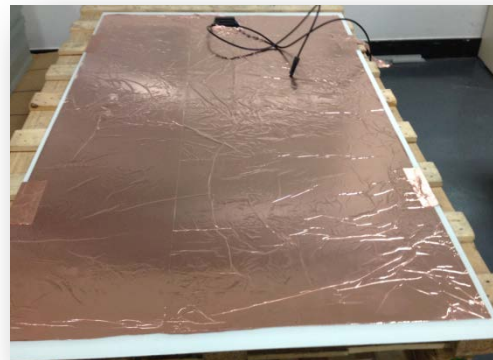
Fabrication of the first batch 300pcs of modules

Bifaciality of 93%

Front side	280W	285W	290W	295W
Distribution	2%	22%	62%	14%

Calibrated with reference modules tested in Fraunhofer Callab.

Rear contribution	10%	20%	30%
Total power	317W	344W	370W



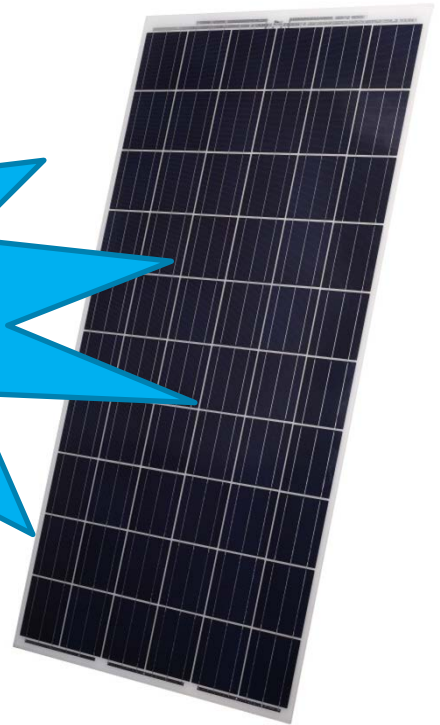
☐ Reliability:

- ✓ LID < 1%
- ✓ TC300 < 2%
- ✓ Mechanical loading < 2%
- ✓ PID < 2%
- ✓ Hot spot defined by UL and IEC
DH+ML and TC+HF ongoing

Reliability: Dual Glass PV Module Design (DuoMax)

- Replacing the backsheet of standard modules with another glass panel significantly reduces the reliability risk in harsh climates
- ✓ 2.5mm front glass/2.5 back glass
- ✓ Both heat-strengthened
- ✓ Frameless
- ✓ 60 or 72 cells
- ✓ Mono or Multi
- ✓ White reflective EVA or transparent EVA
- ✓ Designed for 1500V max system voltage (IEC 1500V & UL1000V certified)

900MW modules sold
No.1 market share



108kW fish culture & PV system in Changzhou

- Location: Menghe, Changzhou
(31° 59'11.4"N, 119° 49'59.9"E)
- Climate: subtropical
- Surroundings: over the lake
- System capacity:
 - 36 kW multi
 - 36 kW bifacial
 - 36 kW bifacial



Same inverter
Same location & Climate
Same operators
Same installation
Same measurement system
“Apple-to-Apple” comparison

Conclusions

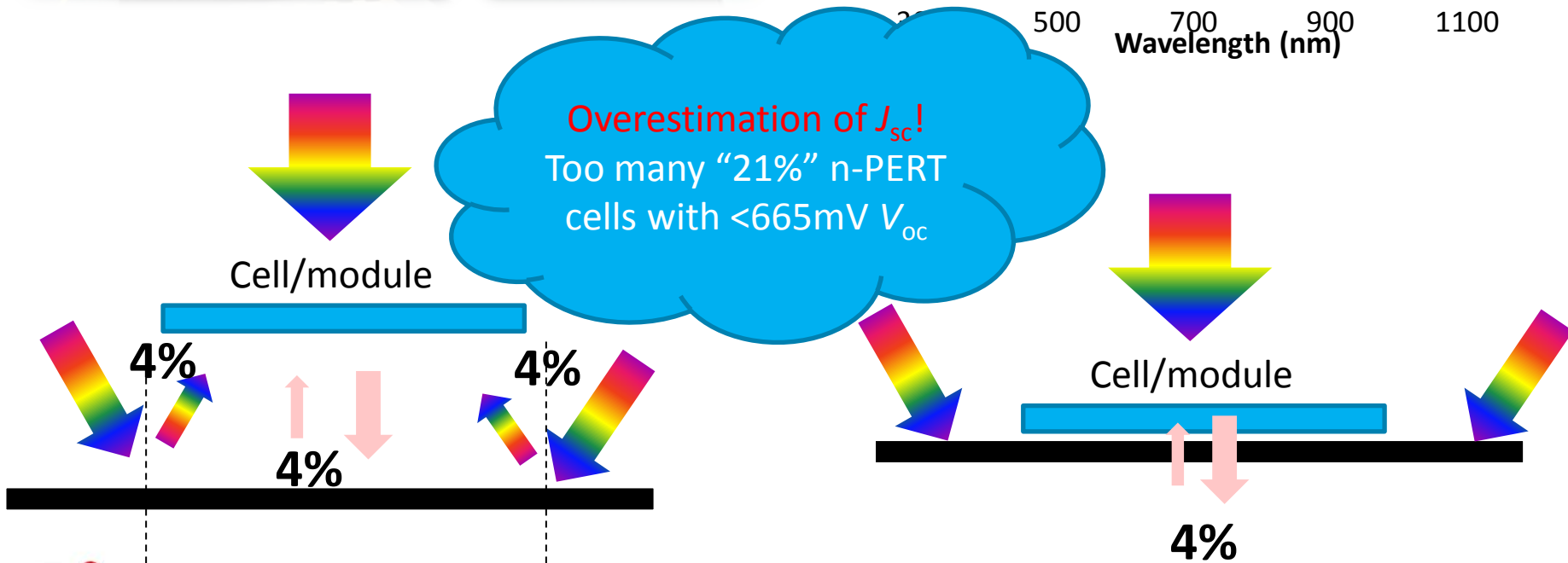
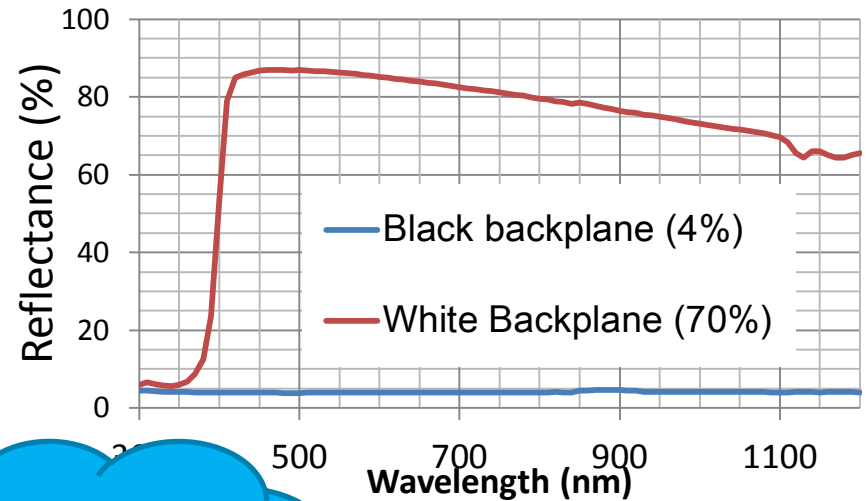
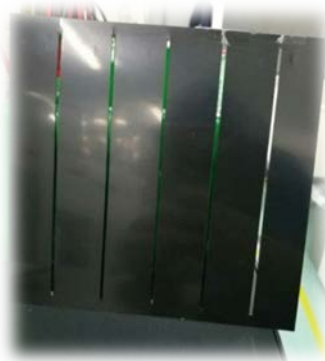
Achievements:

- ❑ Significant progress of n-type bifacial project in Trina Solar since 2016:
 - Power loss analysis indicates that recombination in **the bulk** dominates
 - Improving of technologies yields avg. **21.2%** efficiency and **>670 mV Voc** in pilot line, with best efficiency of **21.7%**
 - Module power **285W-295W (front)** demonstrated with promising reliability

Issues to be solved:

- ❑ **Standard! Standard! Standard!**
 - Black sheet is NOT that black

Issues of bifacial technologies



Conclusions

Achievements:

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Issues to be solved:

- ❑ **Standard! Standard! Standard!**
 - Black sheet is NOT that black
 - Reproducible, measureable, useful for system builders
- ❑ Module and mounting designs still need optimization
- ❑ LCOE should be demonstrated
- ❑ To enter the market, the rear side gain **“X”%** should be clarified
 - **System level** test
 - **“Apple-to-Apple”** comparison

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