p-PERT Bifacial Solar Cell Technology
Past and Future

Dr. Lev Kreinin

Prof. Naftali Eisenberg

SolAround

BIFI Workshop KONSTANZ October 2017

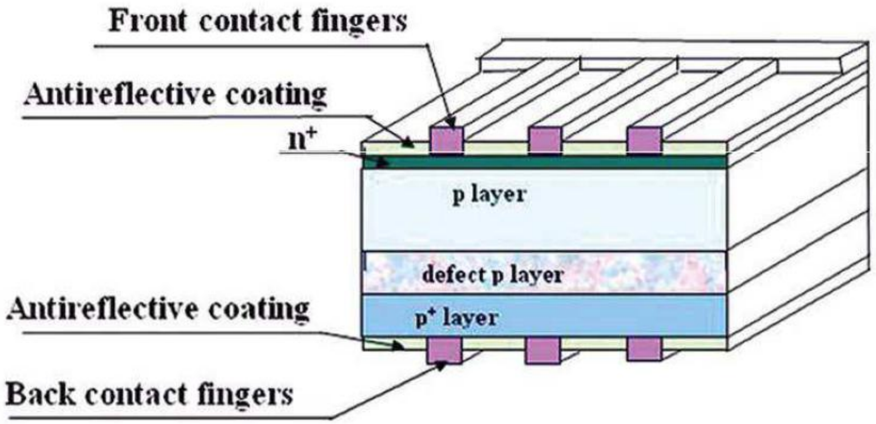
OUTLINE

1. Bifacial p-PERT industrial history in brief
2. Bifacial p-PERT technology
3. Solaround achievements
4. Conclusion

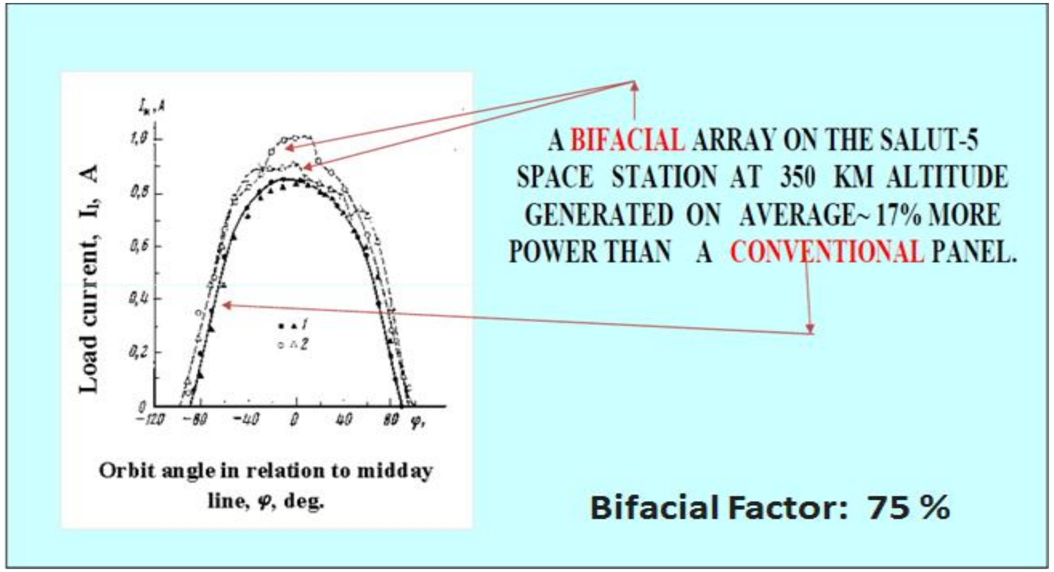
SolAround

1. Bifacial p-PERT industrial history in brief

BIFACIAL p-(P)ERT for SPACE: Kvant, Russia



- p-Si : radiation resistance better than in n-Si
- Thermally doped emitter and implanted back p+ layer
- No front and back texturing
- No front and back passivation but ZnS ARC
- Ti-Pd-Ag evaporated contacts
- η (AMO) = 15-18 %



- Production p-type started in 1958
- Bifacial development started in 1964
- First bifacial satellite in 1974
- Less than 1MW/ year

SolAround

FIRST SEMI-INDUSTRIAL BIFACIAL p-PERT: Solar Wind, Russia

- Production started in 1992 at Krasnodar
- Annual production 2MW/year
- 5” cells with Boron BSF prepared by spin-on boron glass prior to high temperature drive-in
- Bifaciality factor : 70 %
- Front efficiency: 16.5%

Test site: Berlin 2003

6kW on the roof of the ITC, OWZ

3kwp mono-facial and 3kWp bifacial

Albedo: 025   Annual Gain : 8 %

SolAround

FIRST INDUSTRIAL BIFACIAL p-PERT: bSolar, Israel/Germany

- Production started in 2010 at Heilbronn, converting a closed production line of PERT cell with Al-BSF into a PERT line with B-BSF
- Annual production 30MW/year
- 6” cells with Boron BSF prepared by spin-on boron glass prior to high temperature drive-in but cell process different from previous (S-W)
- Bifaciality factor > 78 %
- Front efficiency > 18.5%
- Stopped operating in 2012, together with most of German PV plants

Test site in Adlershof-Berlin 2011

- 27 bSolar panels + 9 reference ones
- bSolar vs. Solon modules
- Ground reflectance (Albedo): **~30%**
- NS distance = **2.35m/3.5m**
- Height (panel lower edge): **0.5m**

SolAround

RECENTLY PUBLISHED LIST OF BIFACIAL TECHNOLOGIES (2016)

Table 1
Selection of conversion efficiencies for different bifacial cell technologies.

Description	Concentration (Sun)	Efficiency (front or front/rear)	Ref.
Buried[a] (independently confirmed)	1	21.9	[80]
Fz-Si p-type triode structure (independently confirmed)	1	21.3/19.8	[81]
Fz-Si (a-Si:H rear surface passivation) (independently confirmed)	1	20.1	[50]
Fz-Si (independently confirmed)	1	19.4/16.5	[82]
Fz-Si symmetrical (independently confirmed)	1	18.4/18.1	[82]
MISIL (independently confirmed)	1	17.1	[83]
Flexible c-Si (thickness: 110 µm, AM0)[a] (independently confirmed)	1	14.7	[81]
CdTe (Cu_xTe back contact, 40–60% transmission) (independently confirmed)	1	13.9	[68]
Si-HJT cell on commercial CZ c-Si 6" wafer using busbar-less front side metallization	1	23.14	[42]
GaAs thin film (thickness: 5 µm)	1	22.6/12.9	[71]
Zebra (n-type c-Si)	1	21.3	[84]
nPERT	1	20.63	[85]
n-type HIT screen printed	1	20.2	[86]
Sliver® solar cells	1	19.4	[22]
Remote plasma CVD		> 18/ > 18	[87]
(ITO)/(p^+nn^+)Cz-Si/(IFO) Cu contact 25 × 25 mm^2	3	17.9/17.0	[38]
(ITO)/(p^+nn^+)Cz-Si/(IFO) Cu contact 25x25 mm^2	1	17.6/16.7	[38]
Cz-Si p-type SiNx PECVD and screen printed, industrial process	1	16.6/12.8	[5]
p^+nn^+[a]	7	16.5/13.6	[88]
p^+nn^+[a]	1	15.7/13.6	[88]
GaAs thin film (thickness: 1.5 µm, AM0)	1	15.4	[89]
CIGS	1	15.2	[70]
POWER cell (16% transparency)	1	12.9	[90]
CdTe/CdS (ITO back contact)	1	10.3/2.1	[16]
Flexible dye-sensitized (if 90° bending: −6%)	1	6.8	[65]
Dye-sensitized (Ti foil based flexible)	1	6.55/4.79	[66]
Dye-sensitized (polypyrrole counter electrode)	1	5.74/3.06	[67]
Ultra-thin CdTe (0.68 µm)	1	5.7/5.0	[69]
Solid-state dye-sensitized solar cell (tandem – no color distortion)	1	3.3	[18]
Organic (50% transparency)	1	3.24	[91]
Simulated n-type HIT		27.02	[21]

[a] Not under standard test conditions.

Bifacial solar photovoltaics – A technology review
by
R. Guerrero-Lemus, R. Vega , Taehyeon Kim, Amy Kimm, L. E. Shephard
in
Renewable and Sustainable Energy Reviews 60 (2016) 1533–1549

400 papers screened on bifacial cells
One p-PERT only in the list

SolAround

NEW BIFACIAL p-PERT APPROACH: SOLAROUND, ISRAEL

MOTIVATION

- p-type mainstream monocrystalline silicon
- PERT structure with full Boron BSF and passivated back is intrinsically superior to local BSF or full passivated structures.
- Highest front efficiency
- Maximum bifaciality

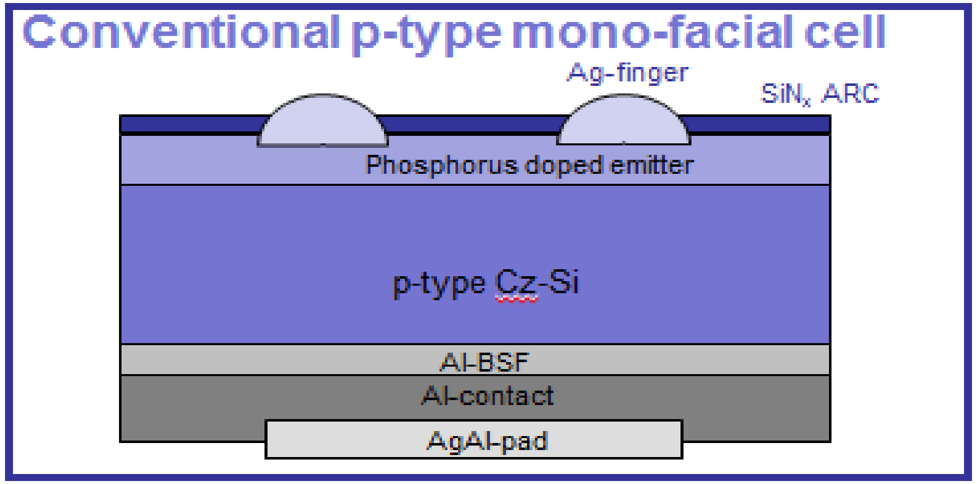
SOLUTION: p-PERT CELL

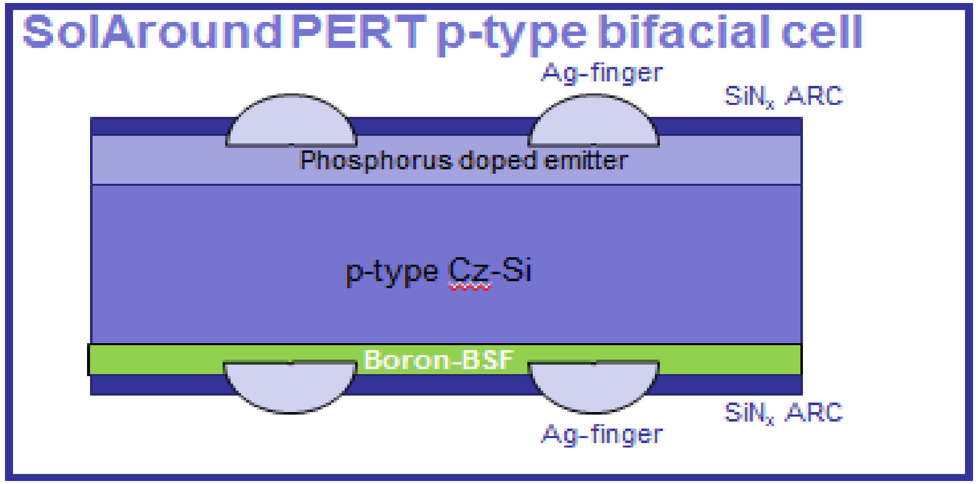
- THE NOVELTY : New Boron Controlled Doping technology using surface deposited layer
- SolAround's solution provides also Boron doping process without degradation of the bulk lifetime

SolAround

2. Bifacial p-PERT technology

p-SI PERT CELL CONCEPTS





Aluminum BSF

- Opaque back side, prevents bifaciality
- Limits increase of front efficiency

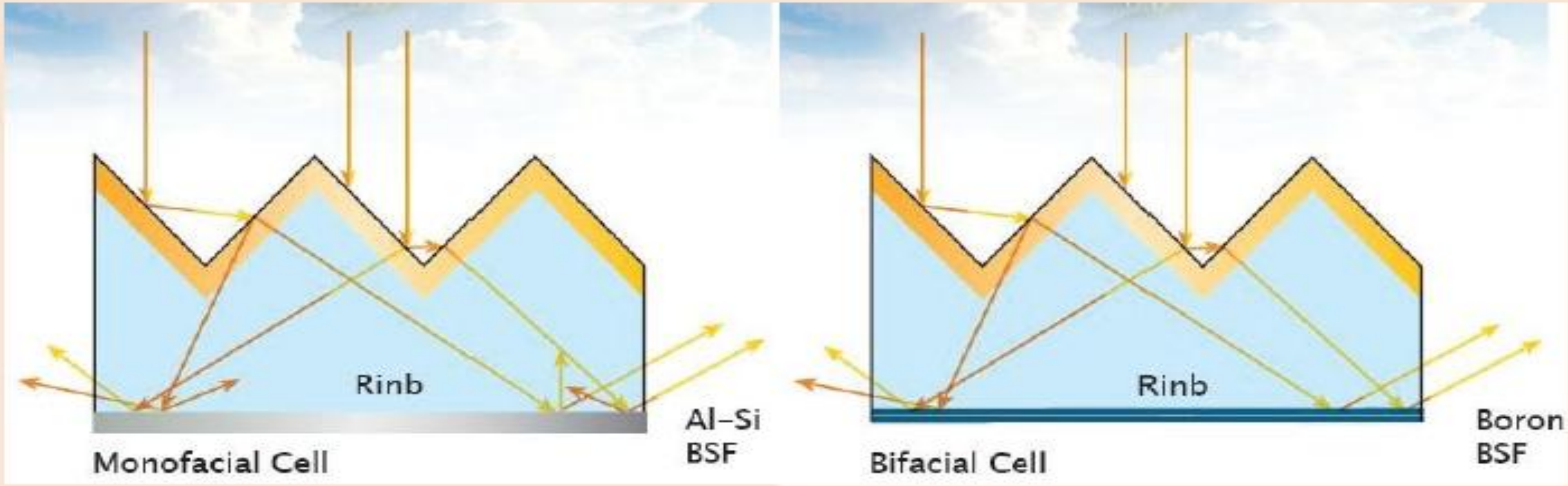
Boron BSF

- Improved front efficiency due to superior BSF (higher B solubility)
- Improved optical properties
- Open back side, allows bifaciality
- Drawback: potential “lifetime killer”

SolAround

COMPARISON OF Al-BSF VERSUS BORON-BSF

INTRINSIC FACTORS OF FRONT EFFICIENCY IMPROVEMENTS OF A BIFACIAL COMPARED to MONO FACIAL CELL



Light trapping and recombination improvements

$R_{in\ b}$ = 60 %	$R_{in\ b}$ = 76 ± 5 %
Al solubility in Si ~3.10^{18} cm-3	B solubility in Si > 10^{20} cm-3
S_{eff} = 400 ÷ 1000 cm/s	S_{eff} < 10 cm/s

PARAMETER REQUIREMENTS FOR n^+-p-p^+ PERT (BIFACIAL) CELL

Electro-Physical Parameters:

- High bulk diffusion length **L >> d (d: cell thickness ~200 microns)**
- High potential of back high-low barrier (BSF)
- Low effective back surface recombination (S_{eff}), at least one order of magnitude less than in Al-BSF i.e**. less than 10 cm/s**.

Optical Parameters:

- Effective light trapping in photoactive wavelength region
- Light rejection in non-photoactive wavelength region

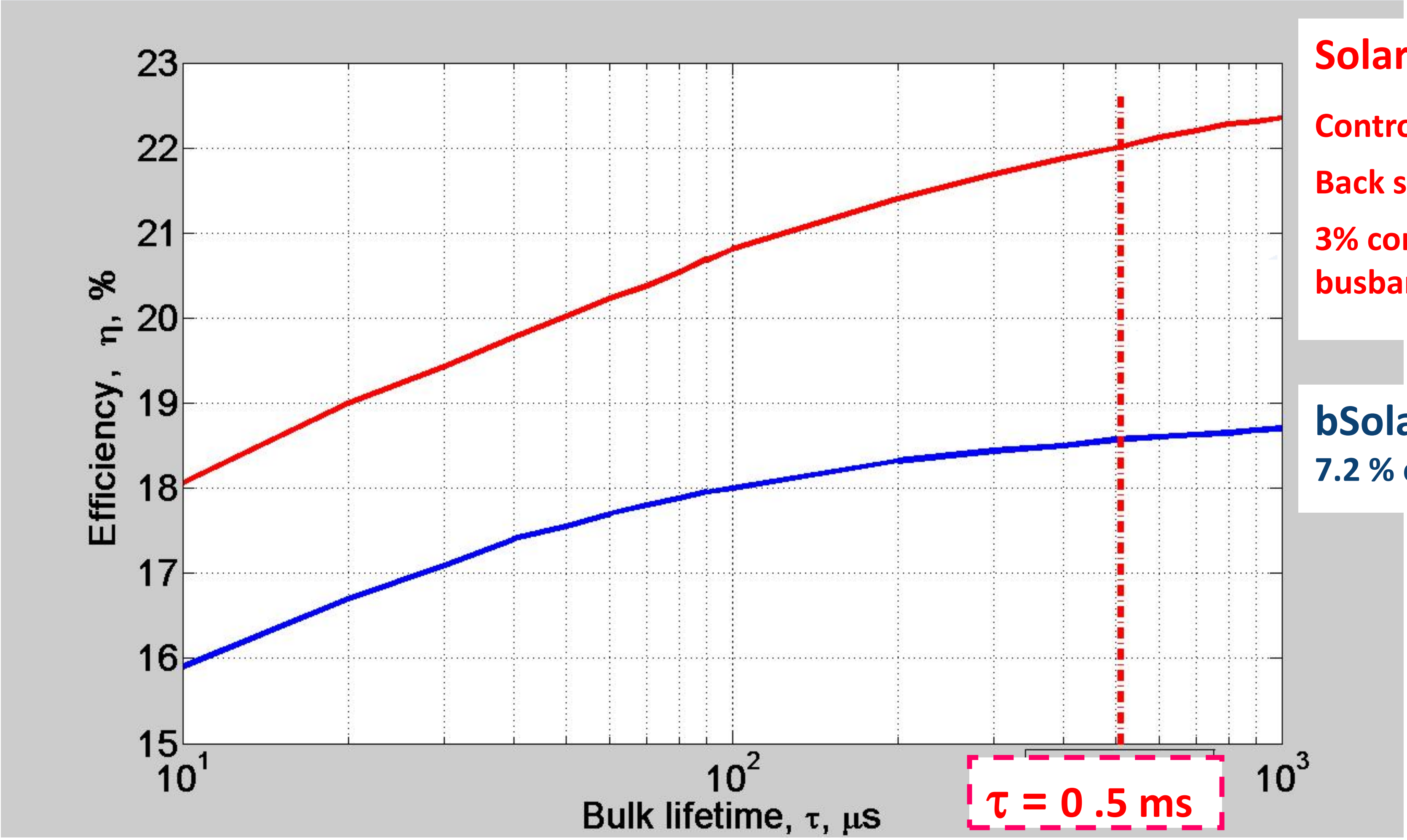
SolAround

NECESSARY ACTIONS FOR ACHIEVING OBJECTIVES

- Use starting Si with high lifetime τ
- Retain τ during cell fabrication
- Proper p^+ layer doping
- Proper pyramid textured on front
- No texturization on boron doped (back) side

SolAround

EXPECTED FRONT EFFICIENCY FOR BIFACIAL CELL WITH B-BSF



Solaround technology with:

Controlled B doping

Back surface passivation

3% contacting surface and floating busbar

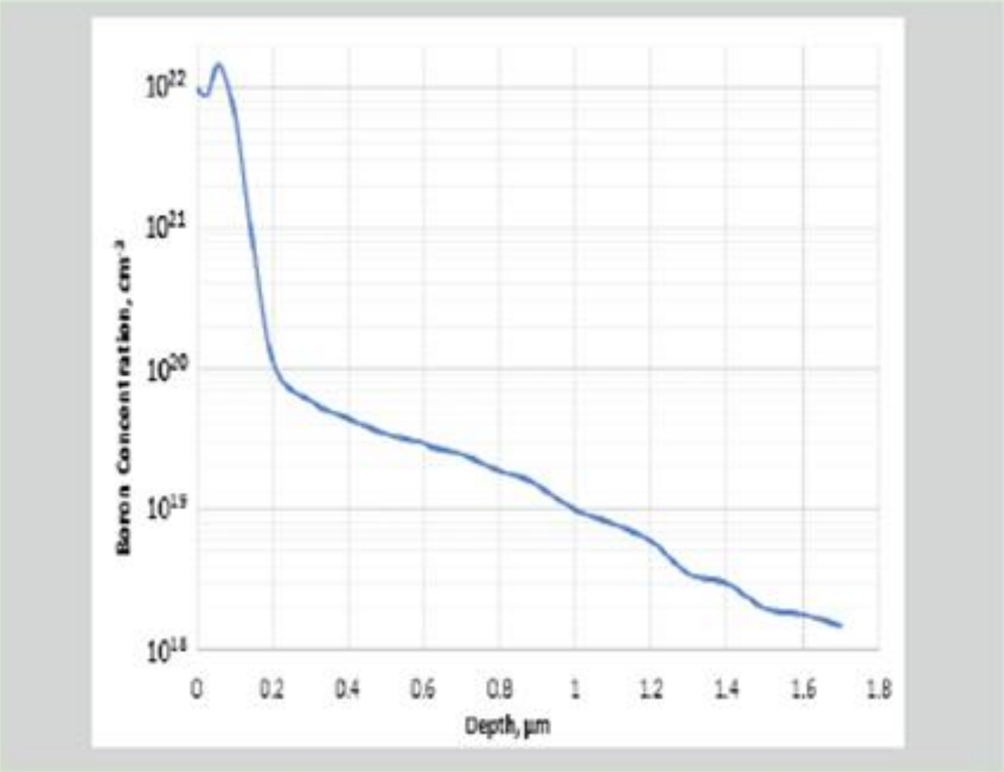
bSolar industrial technology

7.2 % contact coverage

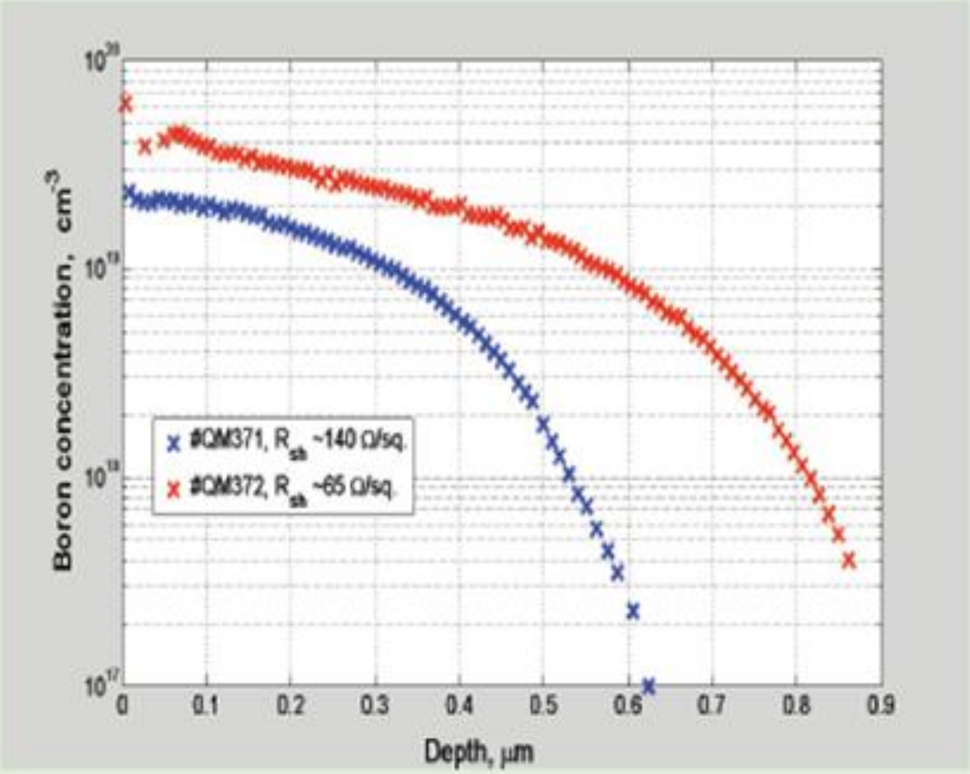
3. Solaround achievements

BORON DOPING OF p^+ LAYER

Over doping
(first generation solar cell)



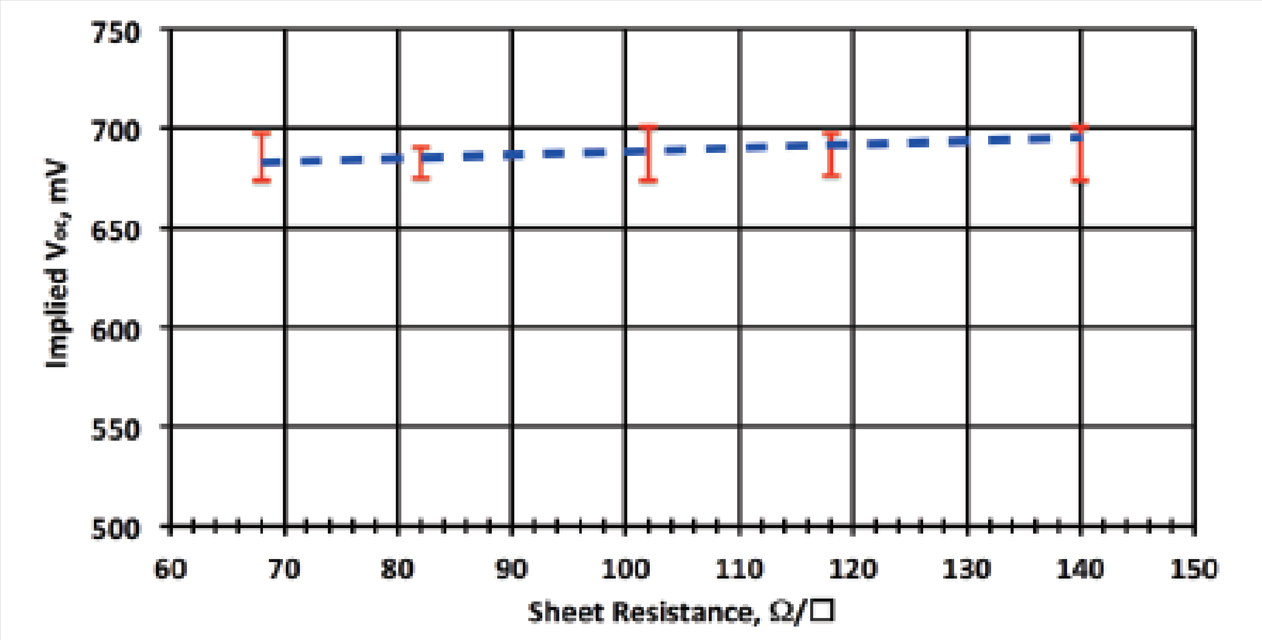
Controllable doping
(new generation solar cell)



SolAround

PRELIMINARY RESULTS WITH NEW BORON BSF PROCESS

Implied open circuit voltage, iV_{oc},
(of n^+-p-p^+ structures vs. doping level of a p^+ layer)

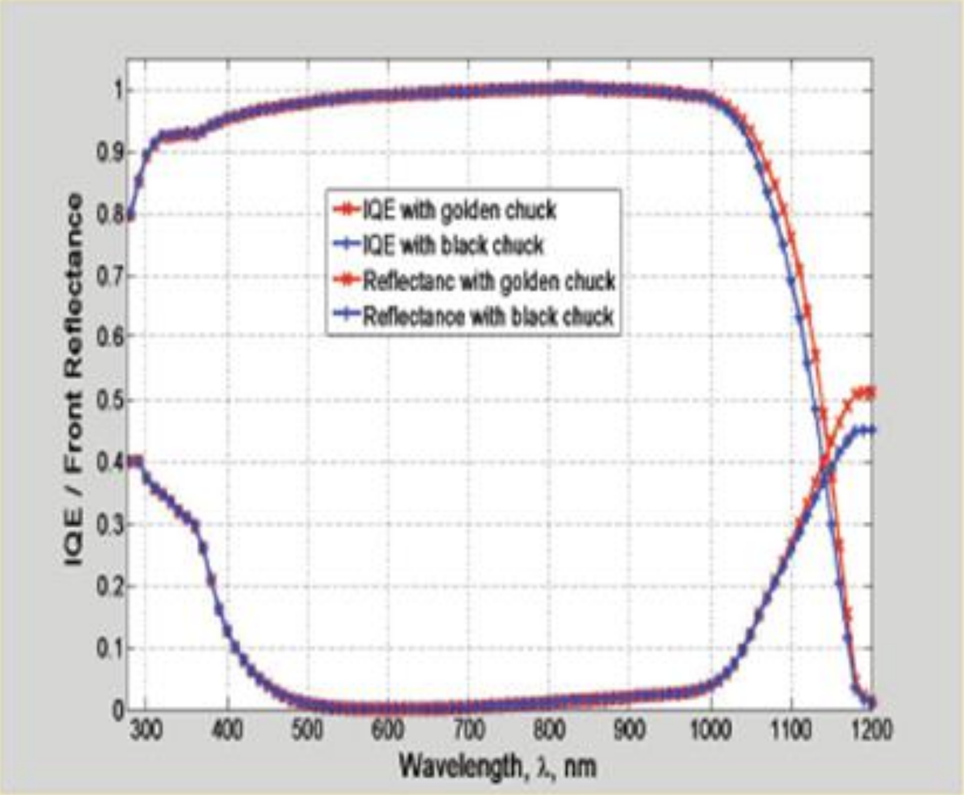


R_{sheet}, Ω/□	68	82	102	118	140
J_0, fA/cm^2	42	58	36	42	34

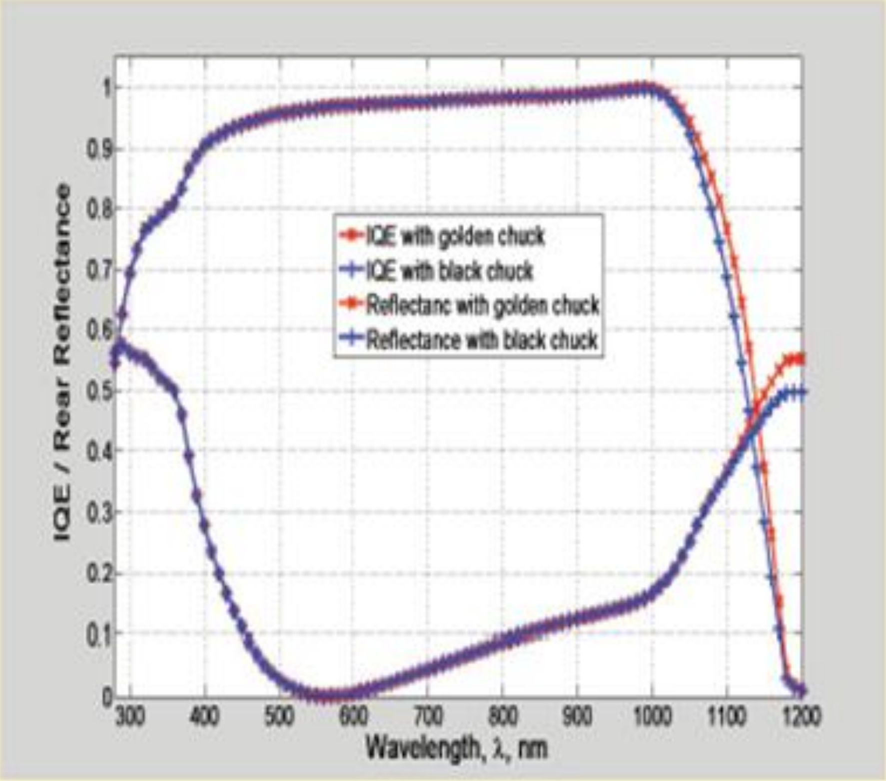
SolAround

SOLAROUND CELL BIFACIALITY

Front IQE

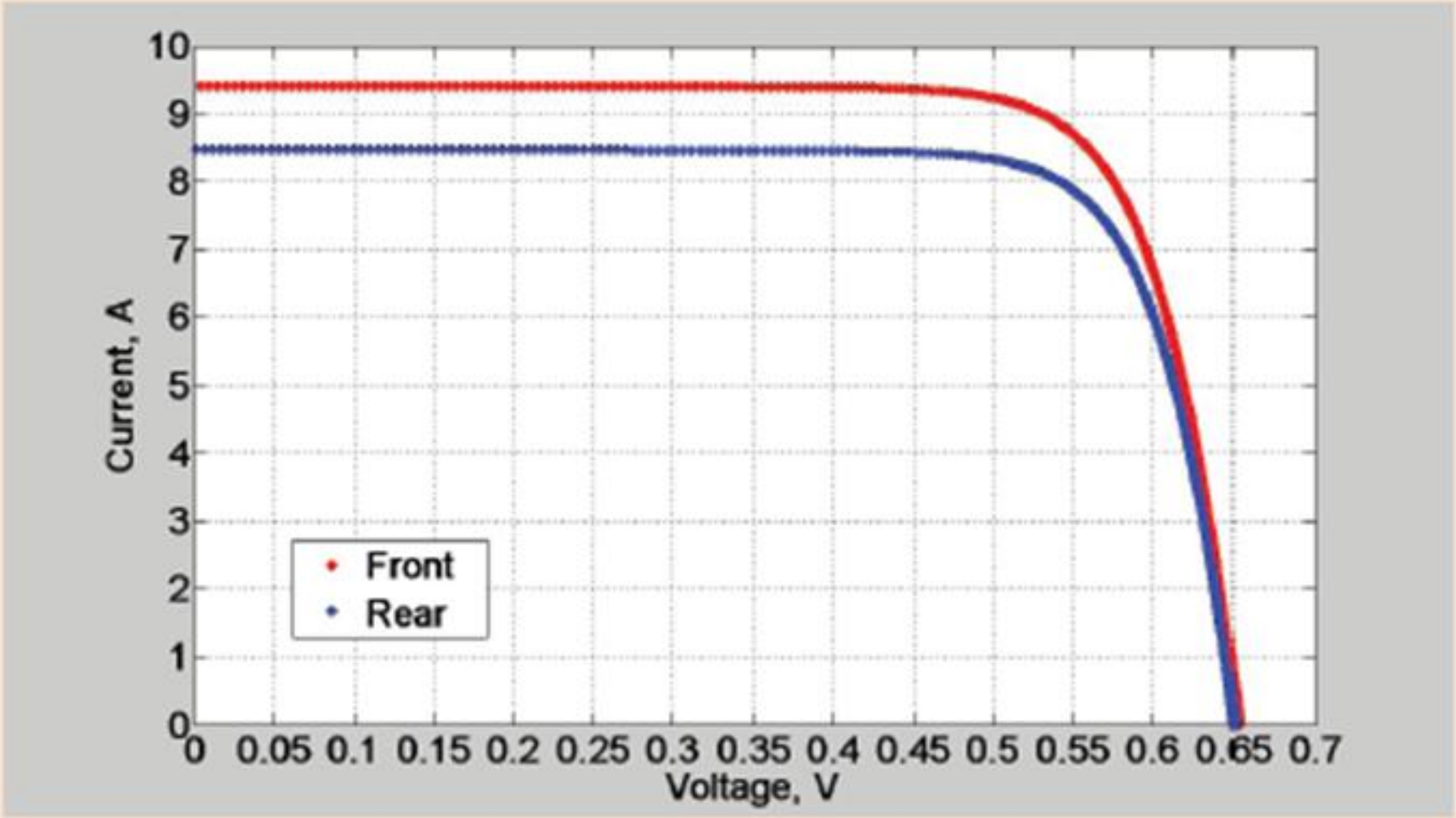


Back IQE



SolAround

SOLAROUND BIFACIAL CELL PARAMETERS



Parameter	Range	Expected
I_{sc}, mA/cm^2	39.2 – 39.5	>40
V_{oc}, mV	650-658	>660
FF, %	78-79	>80
Eff (front), %	19.9 - 20.3	>21
$I_{sc\ b}/I_{sc\ f}$, %	89-92	>92

SolAround

4. Conclusions

- n^+-p-p^+ with a uniformly B doped p^+ layer is a promising structure for industrially produced PERT bifacial cells.
- B diffusion using preliminary deposited B containing solid layer allows controllable doping of p^+ layer.
- Retained high bulk lifetime, low back S_{eff} and high quality emitter provide implied V_{oc} of the PERT structure exceeding 700mV enabling **high front efficiency in the range 21-22 %.**
- **High bifaciality factor**: Back to front short circuit current ratio is in the range **89-92%.**
- High quality Cz starting p-Si can compete with n-Si as material for cell production with front efficiency above 22%.

SolAround

Contact Us

Headquarters:
Lev Academic Center,
21 Havaad Haleumi St.,
Jerusalem 9372115 Israel

Avishai Drori, CEO
avishai.drori@sol-around.com
Mobile: +972 54 5900053

Prof. Naftali Eisenberg, CTO
eisenberg@sol-around.com
Mobile: +972 54 7343468

SolAround