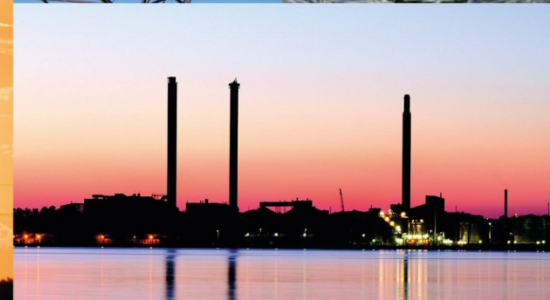
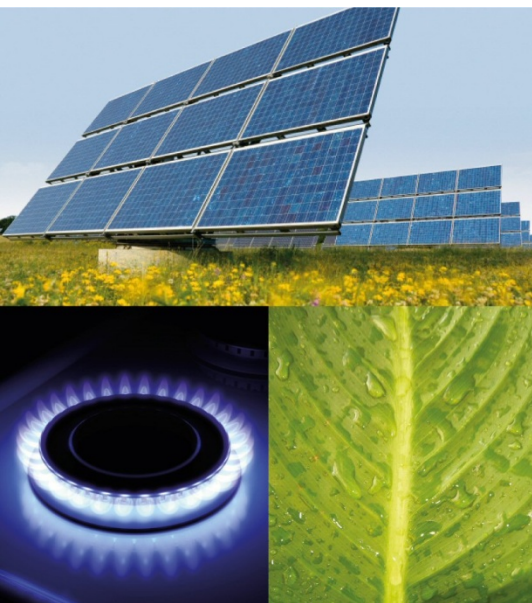


19.5% efficient n-type solar cells made in production

Teun Burgers



Panda project partners and co-authors



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Xiong Jing Feng

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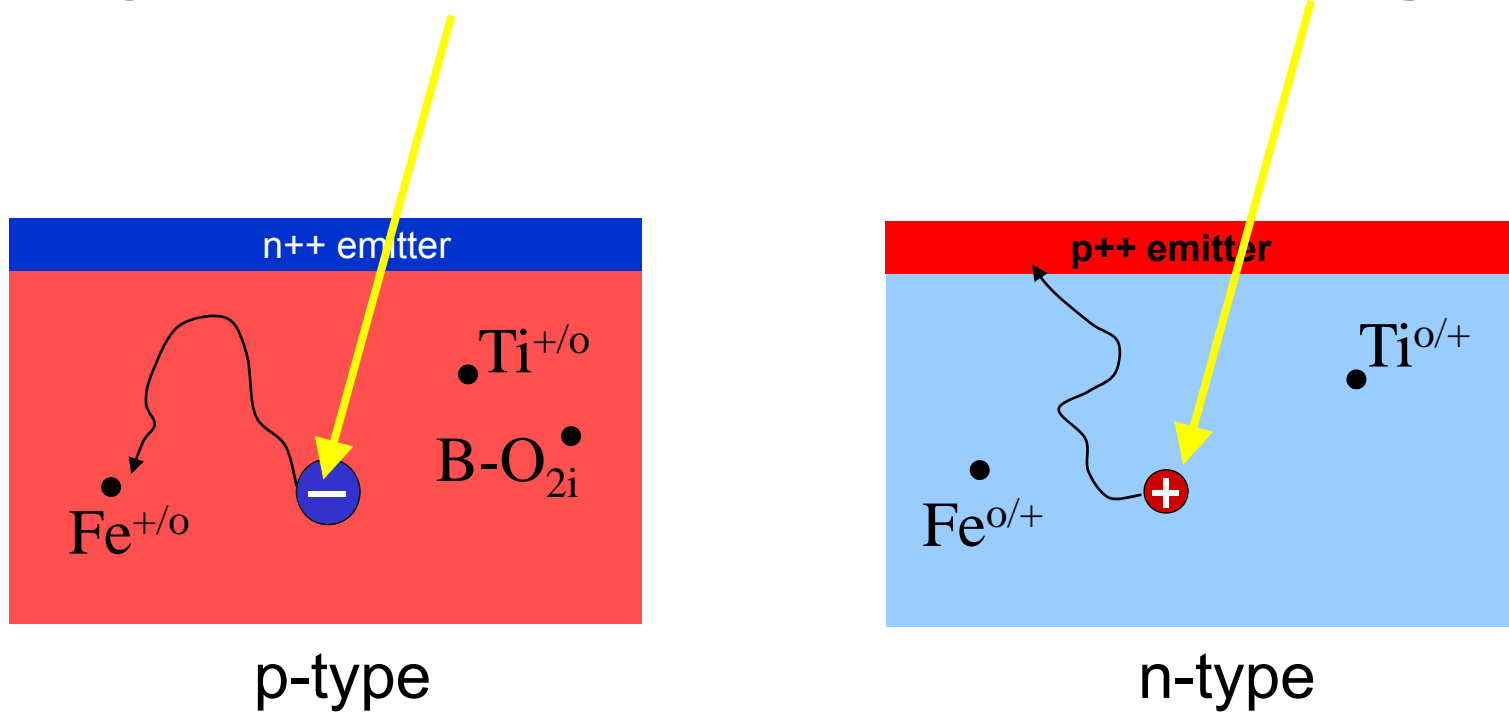
Ard Vlooswijk

PANDA project: n-type cells in production

- ECN
 - Cell technology
 - Initial process specs
 - Process optimization and improvement.
- Tempres (subsidiary of Amtech Systems)
 - Diffusion and glass removal equipment
 - Optimization of diffusion processes
- Yingli
 - Creating and operating pilot- and production lines
 - Technology improvements
 - Module manufacture and certification

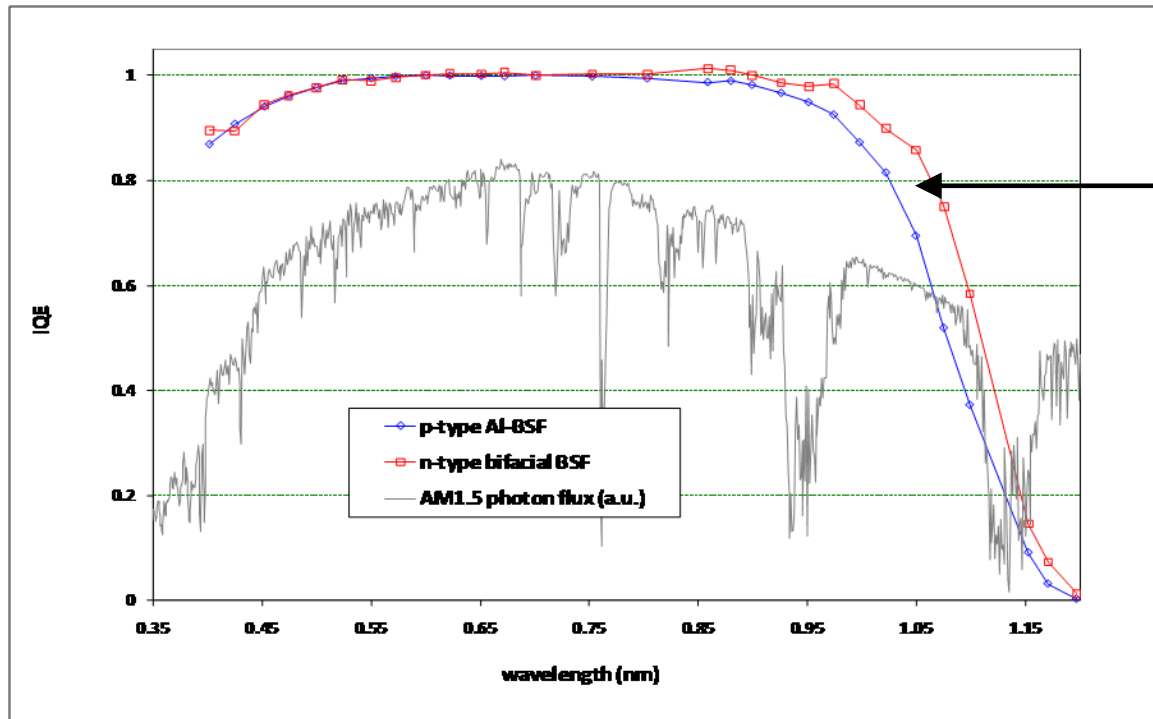


n-type wafer offers better diffusion lengths



- Major metal impurities affect n-type less
- B in Cz wafer: boron-oxygen recombination centre.

n-type vs p-type



Difference is result of:

- bulk diffusion length
- rear optics
- rear passivation

Comparison industrial p-type and n-type cells:
 ~17.5% and 19.5% efficiency

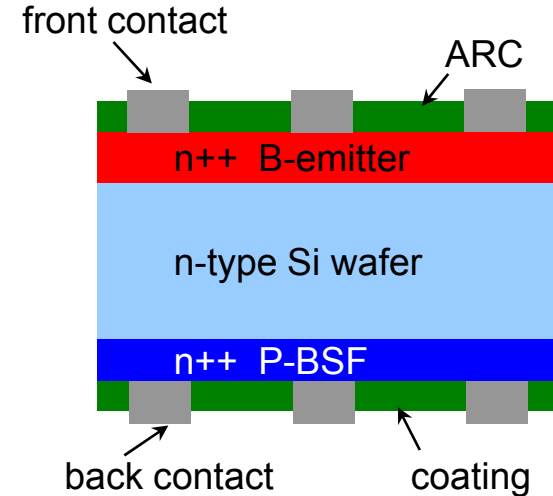
n-type silicon: challenges and breakthroughs

- Diffusing boron emitters
 - *Boron tube diffusion on industrial scale*
- Creating oppositely doped layers on front and back
 - *Different process orders demonstrated*
- Contacting p-type emitters
 - *Successful effort by different and increasing number of paste manufactures.*
- Boron emitter passivation
 - *$\text{SiO}_x/\text{SiN}_x:\text{H}$ stacks*
 - *AlO_x*

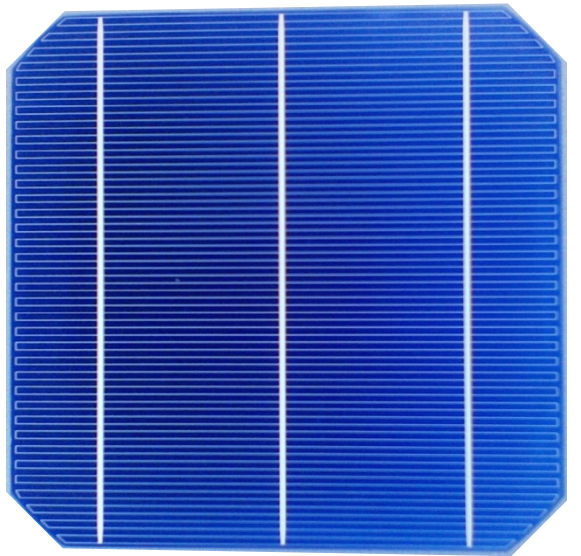
n-type solar cell processes feasible for industrial use.

Features of the PANDA cell

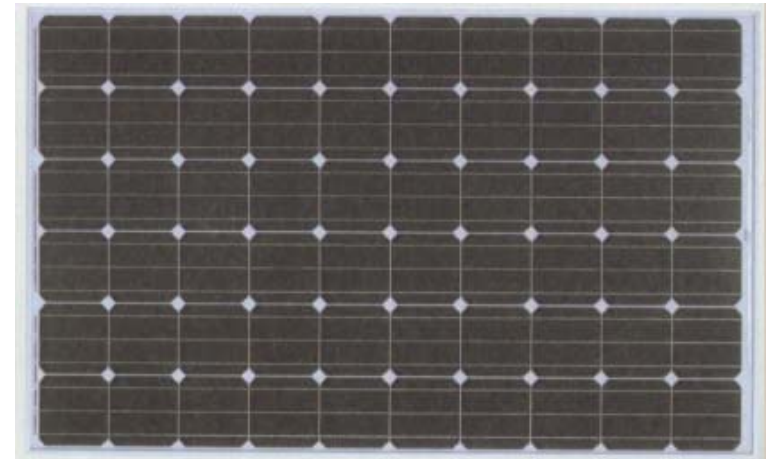
- n-type material for good efficiency
- Bifacial cell, on 6 inch Cz wafer.
- Phosphorous BSF
 - lateral conductivity, good FF
 - rear surface passivation
 - better optics than Al BSF
- No aluminium BSF: no bowing of cells, suitable for thin wafers
- Industrial processing
- Metallization:
 - industry compatible screen printing
 - open front and rear: limited coverage and paste consumption
 - compatible with standard module manufacturing technology



Panda n-type solar cells and modules



← 156 mm →

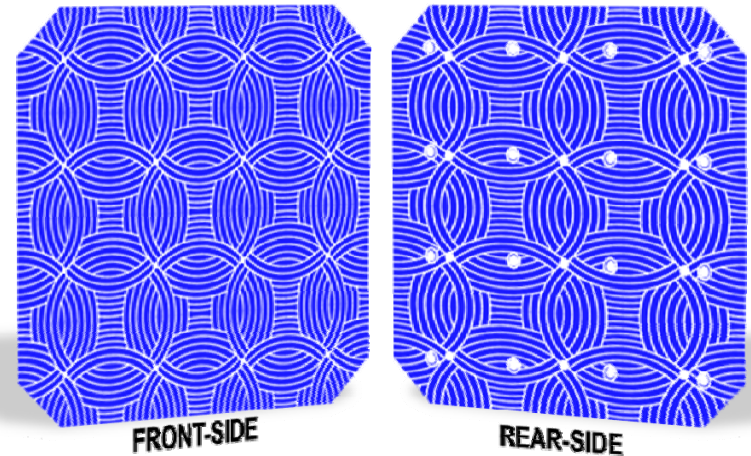


YL265C-30b

Production efficiency: 19.5% (confirmed at FhG-ISE)

Towards improved efficiency

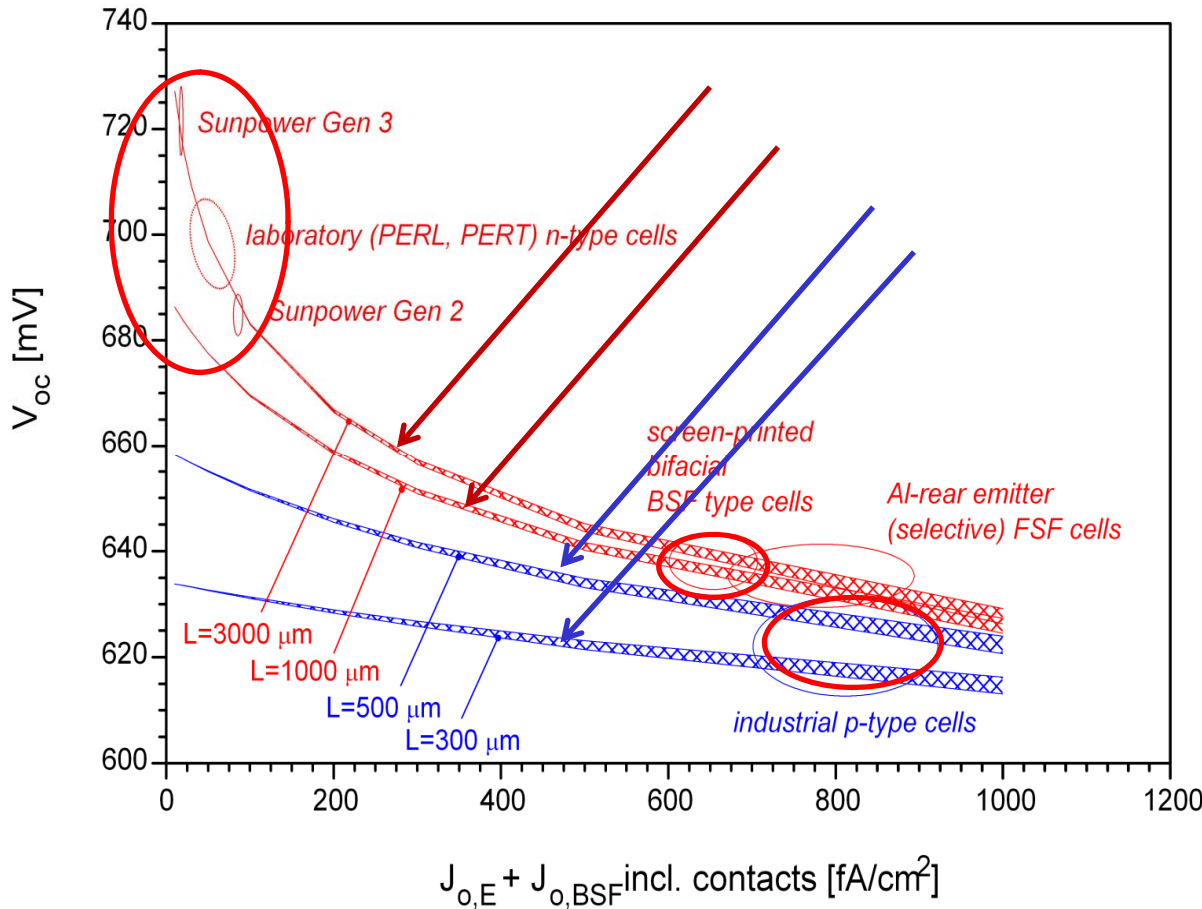
- Combination of n-type Panda process with MWT technology
- Talk 2BO.8.2 by Nicolas Guillevin



$t = 200\mu\text{m} - \text{area}=239\text{cm}^2$		Material	J_{sc} [mA/cm ²]	V_{oc} [mV]	FF [%]	η [%]	R_{se} [Ω]
Average (4 cells)	n-PasHa	Cz-Si ($\rho \approx 5 \Omega\cdot\text{cm}$)	38.4	638	78.9	19.33*	4.6E-3
	n-MWT	Cz-Si ($\rho \approx 5 \Omega\cdot\text{cm}$)	39.5	644	77.1	19.61*	5.8E-3

* measured at ECN (spectral mismatch correction)

V_{oc} : surface recombination and diffusion length

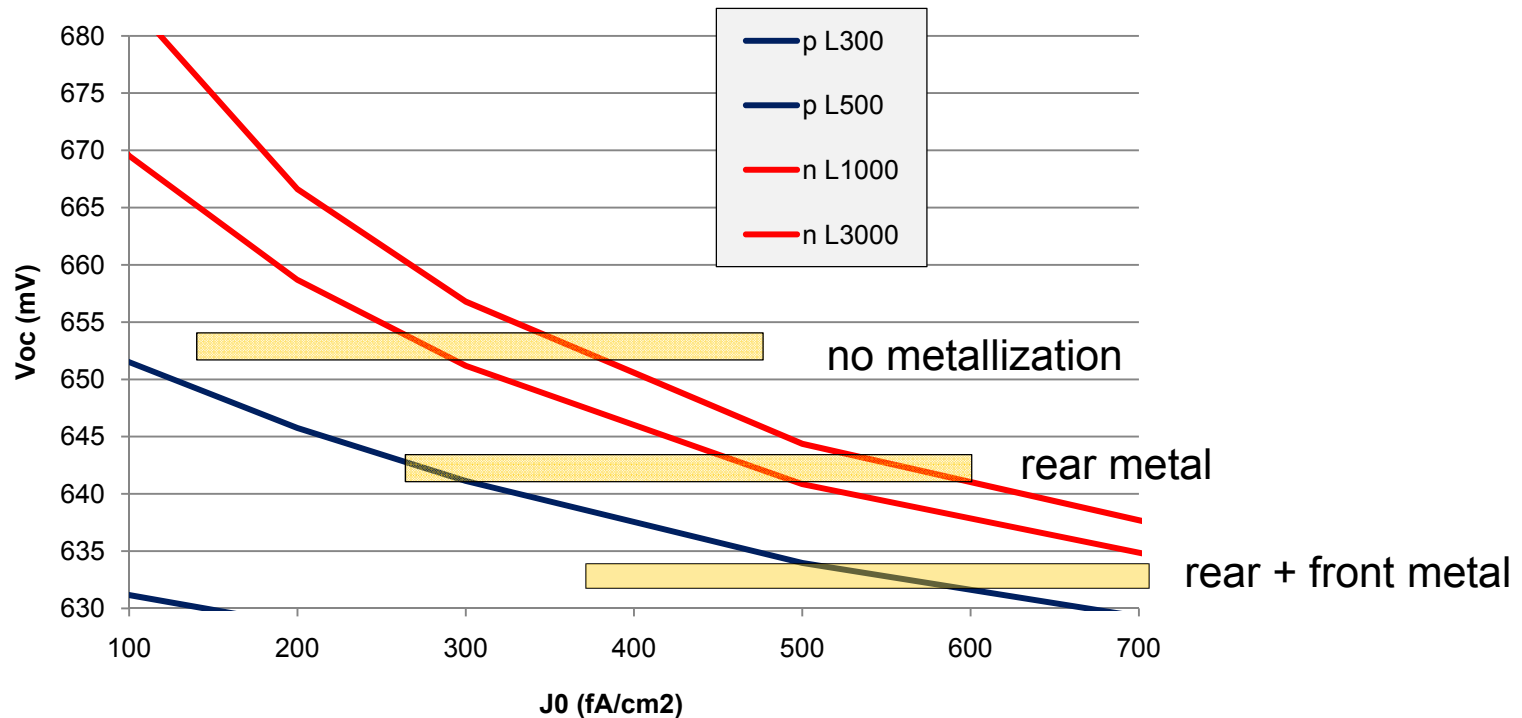


$$V_{oc} = \frac{kT}{q} \ln \left(\frac{J_L}{J_{0e} + J_{0b}} + 1 \right)$$

J_0 sources

- Material
- Contacts
- High doping
- Surfaces

Panda cell: Metallization and (implied) V_{oc}



- No metallization:
 - bulk recombination, heavy diffusions, surface recombination.

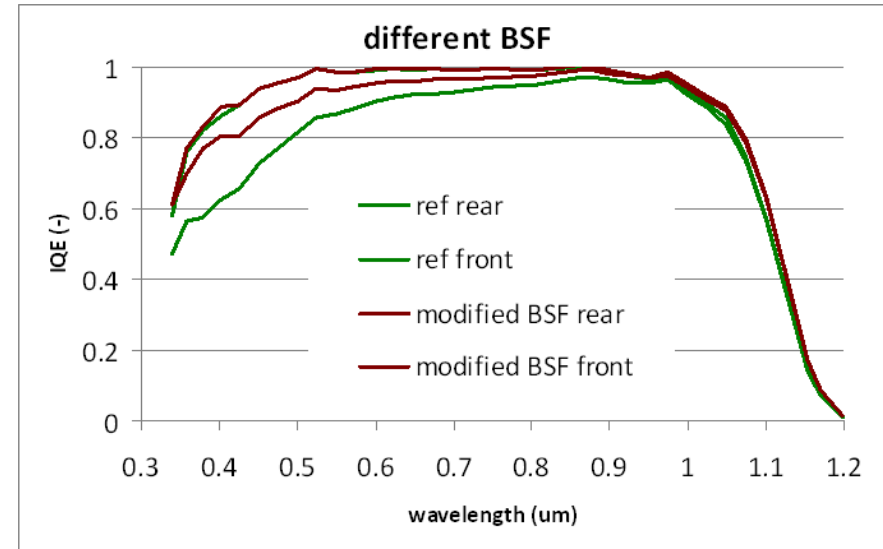
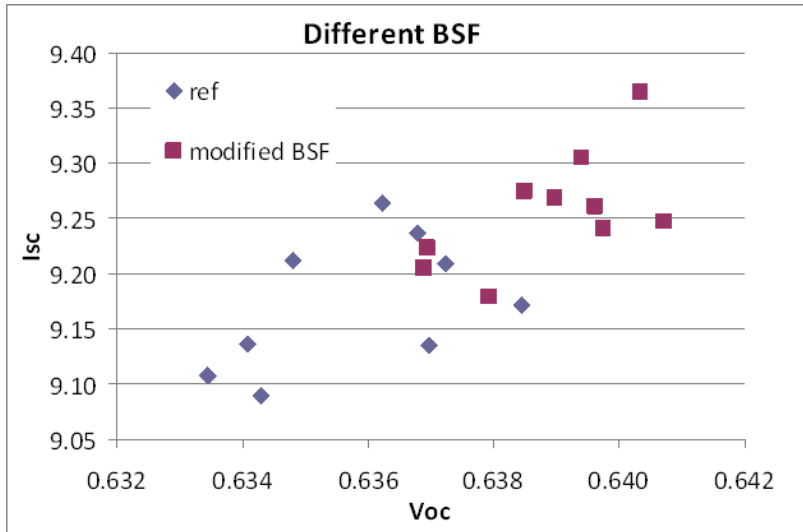
Reducing front contact recombination

Metallization scheme	Isc (A)	Voc (V)	Fill Factor (-)	Efficiency (%)
Reference	9.03	0.629	0.773	18.37
Reduce contact area	9.02	0.633	0.771	18.44

J_0 metal fA/cm ²	Impact on cell J_0 fA/cm ²	Impact on V_{oc}
J_0 : ~3350±350	240±25 for 7.5% coverage	~ 10 - 15 mV 1.3-2.0 mV per % of metal

- Area reduced by 3%
- Voltage improvement consistent with J_0 values

Reduced BSF recombination



Group	I_{sc} (A)	V_{oc} (V)	FF (-)	eta (%)	eta(FF=79.1%)
ref	9.17	0.636	0.791	19.31	19.30
Improved BSF	9.26	0.639	0.741	18.35	19.57

- 0.3% absolute increase in I_{sc} - V_{oc} product
- FF reduced
- IQE front and rear close: bi-faciality

Conclusions

- Over 19% Panda cell efficiency because of
 - high diffusion length n-type
 - rear side with favourable optics, conductivity and passivation
- Potential for further efficiency gains on cell level
 - reduced recombination in diffusions and at contacts
- Potential for efficiency gains on system level
 - exploit bi-facial properties
- Panda project – demonstrates a commercially viable n-type cell