Progress in n-type MWT technology

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Acknowledgment

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n-type silicon cell technology

- Industrial production of bifacial n-type solar cells:
  - Yingli (Panda), 19.6% average, 20.2% best
  - LG (Neon), 21.3% (dual layer ARC and other light trapping features, probably implant)

- Test production and R&D of n-type solar cells:
  - PVGS 20.1% best, 95% bifaciality
  - Bosch 20.7% with implant and inkjet, bifacial
  - Suniva, 20.2% with implant
  - Hanwha Q-Cells, 21.3% rear emitter
  - Motech, 20.2%, bifacial

  and many institutes:
  - ECN, n-Pasha*, 20.2% best
  - ISC, ISFH, INES, imec, FhG-ISE, etc.

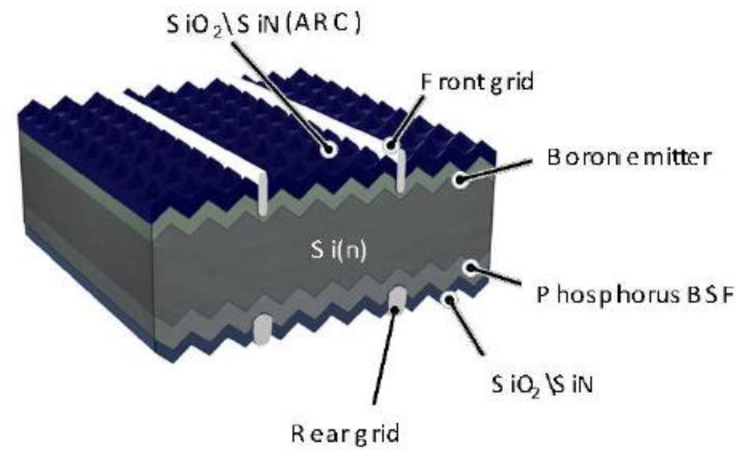


Figure.3: Cross-section of a PERT bifacial cell

Figure from:
Y. Veschetti et al; 28th EUPVSEC, Paris, France 2013
S. Gall et al.; 28th EUPVSEC, Paris, France, 2013

*Pasha=passivated all sides H-pattern

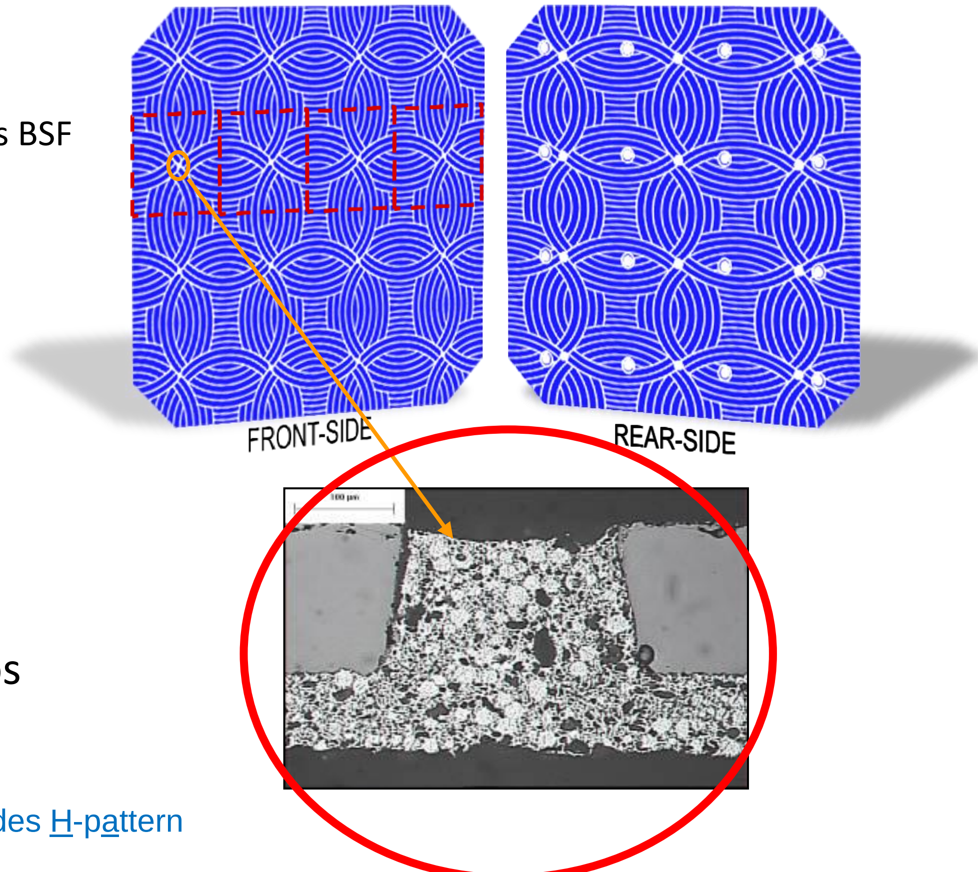
ECN n-MWT cell technology

- N-type bifacial cells
  - n-type Cz substrate
  - front Boron emitter and rear Phosphorus BSF
  - suitable for thin wafers
  - good rear surface passivation:
    higher spectral response in the IR
  - bifacial module application possible

- "unit cell" grid design
  - up to 3.5% less shading
    than front-contact busbar cell

- Simple and industrial process steps
  - similar to industrial process for n-Pasha
  - LASER drilling of via-holes

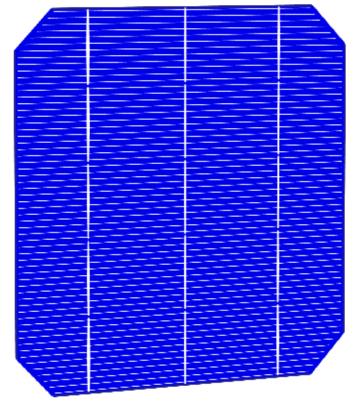
passivated all sides H-pattern



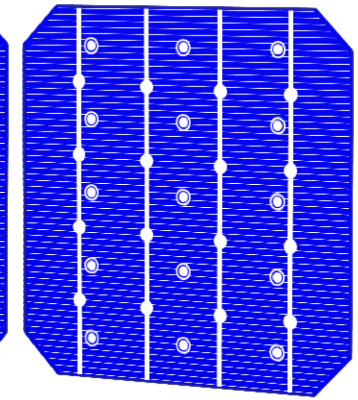
n-MWT and n-Pasha cells

- Experiment aimed at relating MWT-performance to n-Pasha performance
  - same material
  - same diffusion profiles
  - same passivation dielectrics

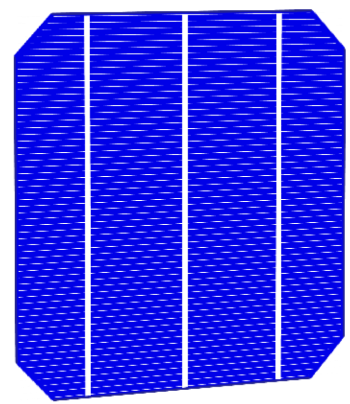
- n-MWT grid design: “H-pattern look-alike”
  - narrower busbars than n-Pasha
  - ≈2.5% less metal coverage than n-Pasha (optimised unit cell grid design would yield further 0.5-1.0% reduction)



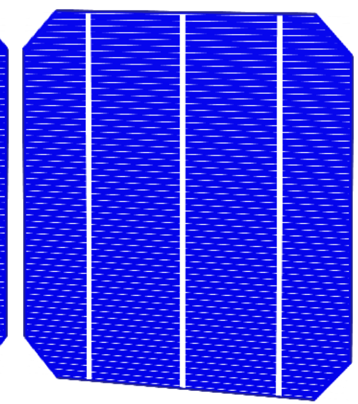
n-MWT – front side



n-MWT – rear side



n-Pasha – front side



n-Pasha – rear side

n-MWT and n-Pasha cells

t = 180µm – area=239cm²		Material	J_{sc} [mA/cm²]	V_{oc} [mV]	FF [%]	η [%]	R_{series} [Ω]
Average (12 cells)	**n-Pasha**	Cz-Si (1.7 Ω.cm)	38.90	652	78.4	**19.90**	4.9E-3
	n-MWT	Cz-Si (1.7 Ω.cm)	39.95	652	76.8	**20.05***	5.7E-3

* measured at ECN
relative to ISE-calibrated Isc-reference
includes spectral mismatch correction
non-conductive, reflective, chuck

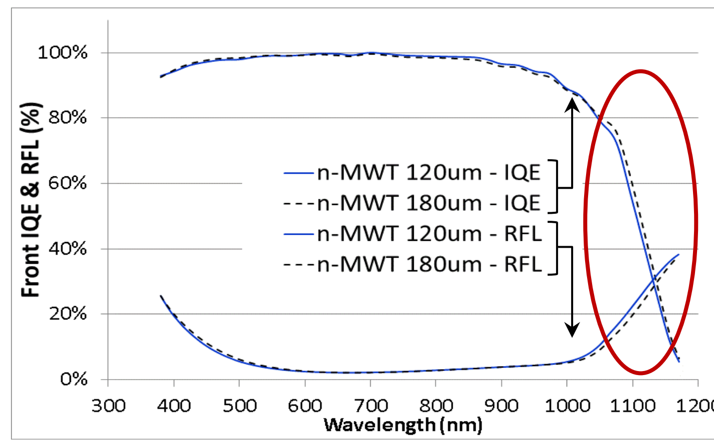
- 2.6% rel. Jsc gain for MWT (+1.4 mA/cm2)
  - Reduced front metal coverage ➔ Less shading
- No Voc gain for MWT
  - Despite reduced metal coverage - due to use of floating busbar paste in n-Pasha
- ≈1.5% abs. FF loss for MWT
  - can be quite well traced to individual series resistance components
  - largest part of loss occurs in narrow mini-busbars

120µm thin n-MWT cells

area=239cm²		J_{sc} [mA/cm²]	V_{oc} [mV]	FF [%]	η [%]	R_{series} [Ω]	Irev @-12V [A]
Average (12 cells)	n-MWT **180µm**	39.95	652	76.8	20.05	5.7	<0.3
	n-MWT **120µm**	39.63	651	76.5	19.74	5.8	<0.3

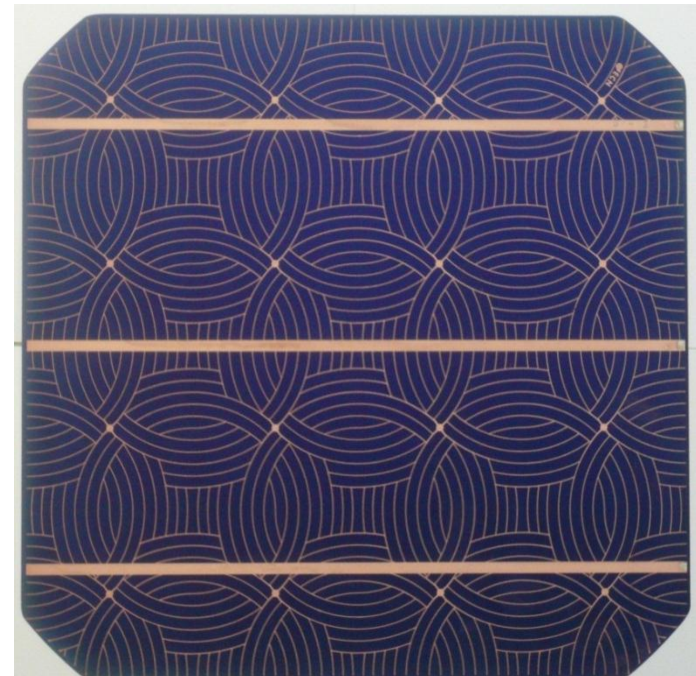
- Identical processing for both groups
- Different material but similar bulk lifetime and diffusion length

- No increase in breakage rate
- Comparable V_{oc} and FF
- 1% rel. lower J_{sc} for the thin n-MWT cells
  - higher escape reflectance due to reduced light trapping
  - Consistent with PC1D modeling



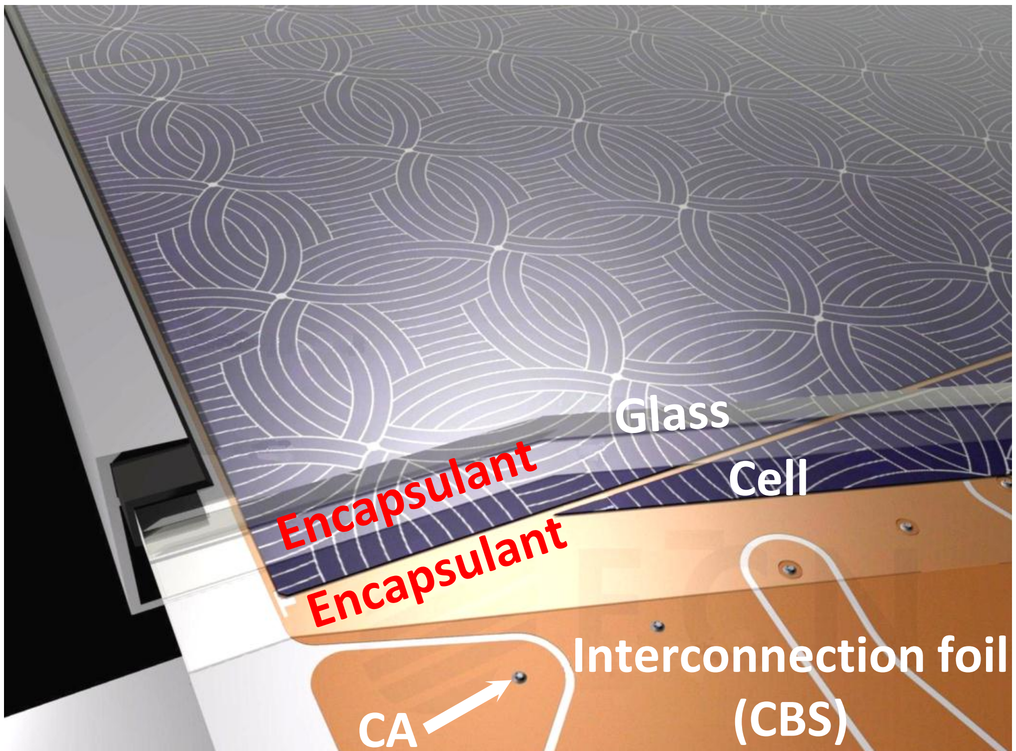
Seed & Cu-plate

- Cooperation with Meco on Cu-plating
- Plate on Ag fire-through seed
- Preliminary results:
  - Rear side plating:
    ΔFF=+0.5% compared to standard
    $\Delta\eta$ = +0.1%$_{abs}$
    Ag reduction
  - Front side plating:
    ΔFF=+0.6%-0.7% compared to reference
    Isc-reduction; need optimised seed
  - Module technology:
    Interconnection on conductive backsheet
    ➔ Cu plated cell grid can be finished with OSP
    ➔ no Sn or Ag cap required
    ➔ cost reduction
  - Module tests so far satisfactory, see
    I. Bennett et al., Photovoltaics Int. , issue 21



Use of hybrid front screen to allow contact on normal busbars in plating tool.

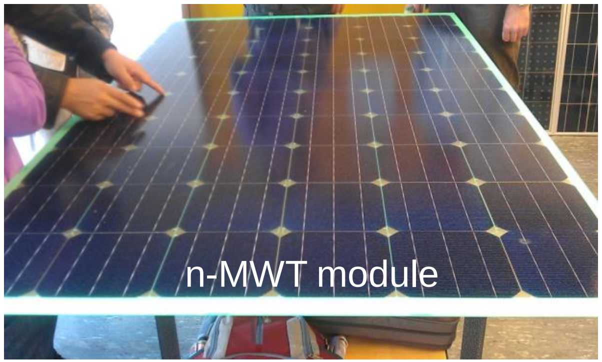
ECN MWT module technology



CA: conductive adhesive CBS: conductive back sheet

- single step curing during lamination:
  CA & encapsulant
- less stress on wafers:
  no tab-around, no soldering
  ➔ suitable for thin wafers
- higher packing density of cells
- low FF loss

n-MWT vs. n-Pasha: module performance

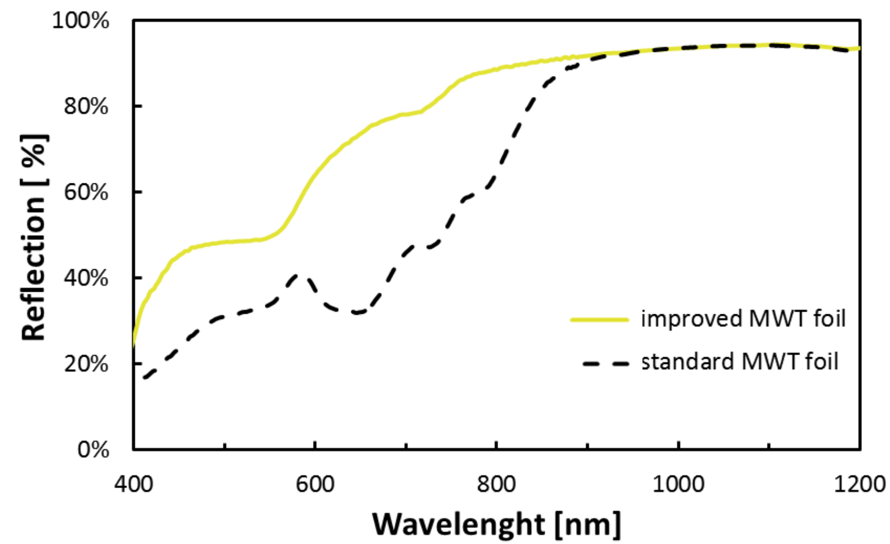


	Cell type	cell η [%]	P_{max} [W]	cell-to-module FF loss [%]
2010	n-Pasha	18.6	265	3.0
	n-MWT	18.9	273	0.8
2012	n-MWT	19.6	**279**	1.3

- **2010:** first 60-cell n-MWT module made and compared to n-Pasha module:
  - very low cell-to-module FF loss of 0.8% abs
  - 3% more power
  - MWT module power limited by back-sheet reflectance
- **2012:** higher cell efficiency & improved back-sheet reflectance:
  - Somewhat higher cell-to-module FF loss than expected (different conductive adhesive used)
  - I_{mpp} mismatch
- **n-MWT module prospect:**
  ➔ with 20% cell efficiency 290Wp expected

Importance of back sheet reflection

foil	Isc CtM change
green (2010)	REF
white (2012) ("improved")	+1.2%

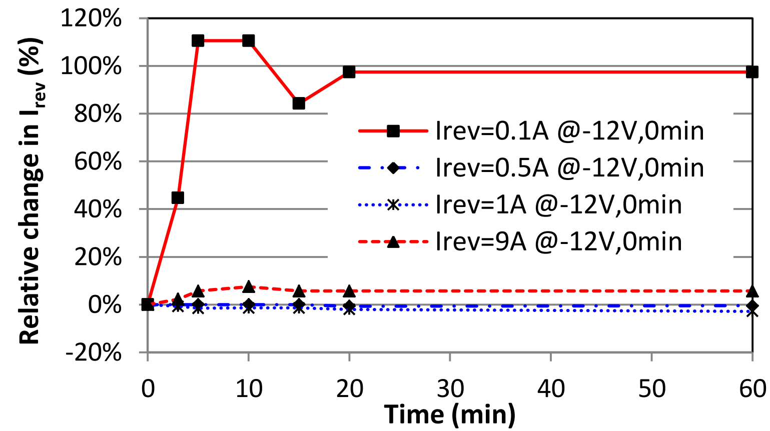


- improved foil is not yet fully optimised for reflection
- 1% current improvement corresponds to 3 W increase in module power

Reverse I-V characteristics

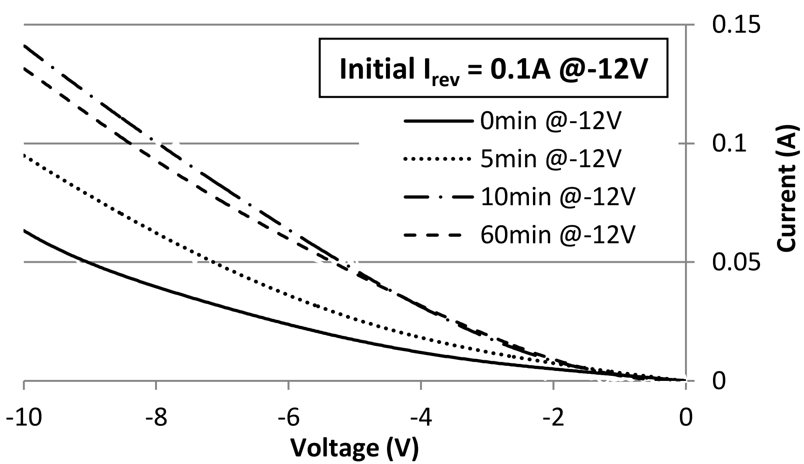
- Test of stability of Irev under reverse bias
- Selection of n-MWT cells with different initial I_{rev}
  - 0.1A, 0.5A, 1A and 9A at -12V
  - I_{rev} located at the rear side emitter contact pads
- I_{rev} @-12V recorded for 1 hour
- I_{rev} stable, or stabilises
  - Relative I_{rev} increase ~100% for the case with lowest initial I_{rev} (0.1A @-12V)

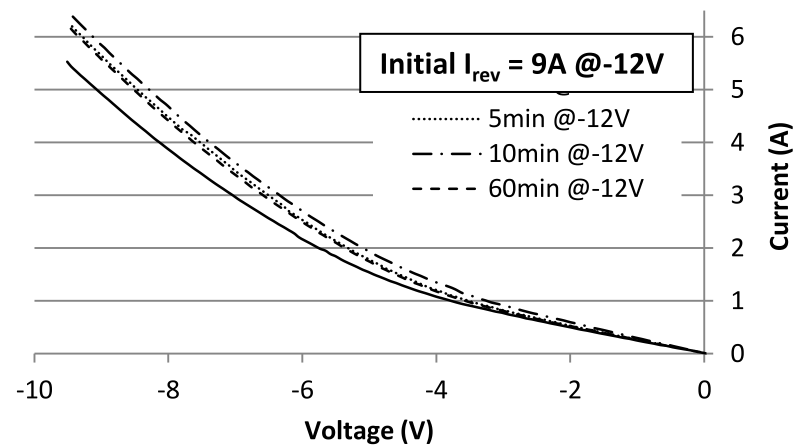
    ➔ I_{rev} level after 1 hour <0.2A @-12V



Reverse I-V characteristics

- Test effect of reverse bias on I-V
- No dramatic change of the dark reverse I-V characteristics
  No increase of the slope at 0V
  (Higher slope at 0V for the high I_{rev} cell (9A @-12V) corresponds to low R_{shunt})





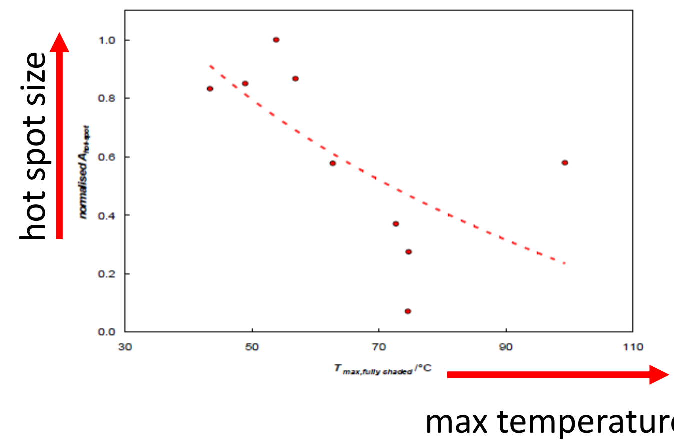
- Prolonged exposure at -12V does not affect forward I-V characteristics

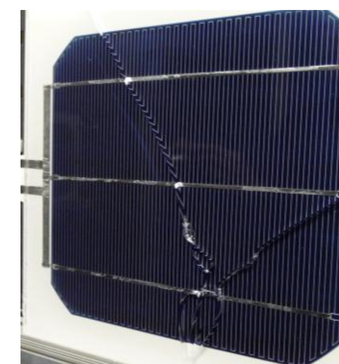
Hot spots in modules

Table I: Critical temperature of the front glass overview

temperature	effect	module consequences
< 150 °C	no visual effects	normal module performance
> 150 °C	melting of encapsulation	delamination and less heat conduction material
> 170 °C	discolouration of the back sheet foil	attenuated of the electrical module isolation
> 200 °C	irreversible destruction of the cell *pn*-junction	performance loss at the module under unshaded conditions

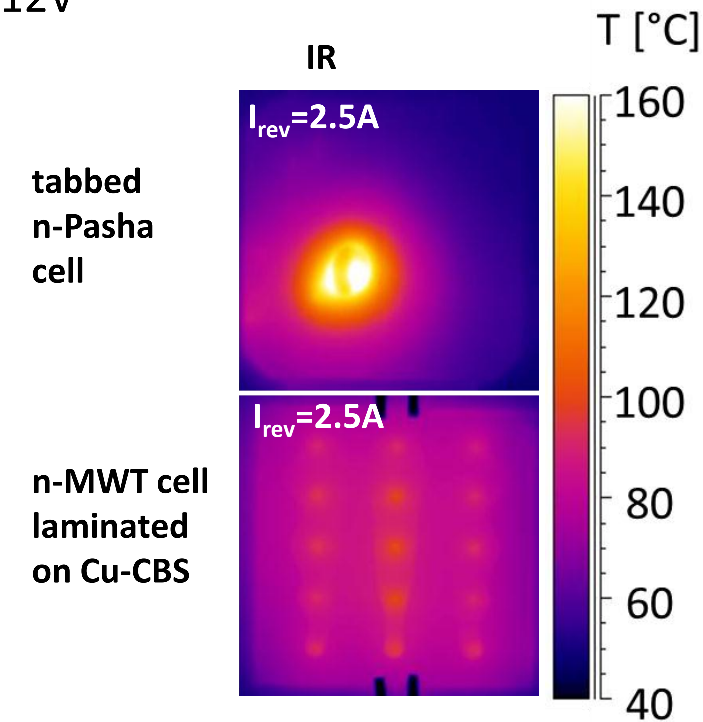
Wendlandt et al. 25th EPVSEC (2010)





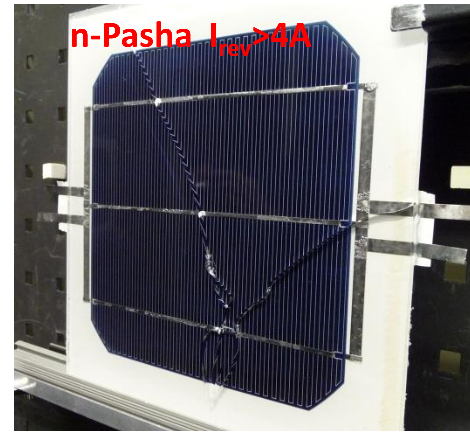
n-MWT and n-Pasha: Tolerance of laminates for hot spots

- Typical I_{rev} of n-MWT and n-Pasha cells <0.5A @-12V
- Selection of cells with a large range of I_{rev}
  - in case of n-MWT: at via-holes
- MWT cells on conductive back sheet:
  - For same I_{rev} as tabbed n-Pasha, lower temperature
- Test: laminates exposed to -10V for up to 1 hour in the dark at 50°C.



n-MWT and n-Pasha: Tolerance of laminates for hot spots

Laminate type	I_{rev} @-10V [A]	Max temp. [°C]	Δη [%]	Visual failure
n-MWT & n-Pasha	>4	>160	> -3	Yes
n-Pasha	2.6	>160	-2	Yes
n-MWT	3.1	105	-0.02	No
n-Pasha	1.3	110	-0.05	No



- I_{rev}>4A: visual failure within few minutes for both types of laminates
- I_{rev}<4A:
  - less heating and no damage for n-MWT with I_{rev} of 3.1A
  - visual damage and η loss for n-Pasha with I_{rev} of 2.6A

➔ Better heat distribution & dissipation in Cu foil for n-MWT laminates

To be investigated: is this the case for general hotspot patterns, or just for hotspots located at the contact pads

Conclusions

- n-MWT results in high efficiency for low cost industrial process
  - $0.15\%_{abs}$ cell efficiency gain over n-Pasha
  - +3% module power gain over n-Pasha tabbed module, potential for >4% gain
  - 20.1% best cell efficiency so far
  - 279Wp module power reached (60 cells), potential for >290Wp
  - Only small efficiency penalty for 120µm thin cell ➔ extra cost reduction opportunity

- n-MWT shows good behavior for reverse operation
  - Process optimized to result in I_{rev}<0.5A at -12V
  - Preliminary results show more optimum dissipation of hot spots than in n-Pasha laminates ➔ less thermally-induced damage than in n-Pasha modules with similar I_{rev}
  - Stable reverse and forward I-V characteristics under prolonged reverse voltage

Thanks to the n-MWT teams at

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Nicolas Guillevin, Benoit Heurtault, Bas Van Aken, Ian Bennett, Mark Jansen, Ingrid Romijn, Astrid Gutjahr, John Anker, Martien Koppes, Arthur Weeber and Jan Bultman

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