ECN
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MWT Silicon Heterojunction

A Simple Technology Integrating High Performance Cell and Module Technologies

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Hercules workshop, Berlin

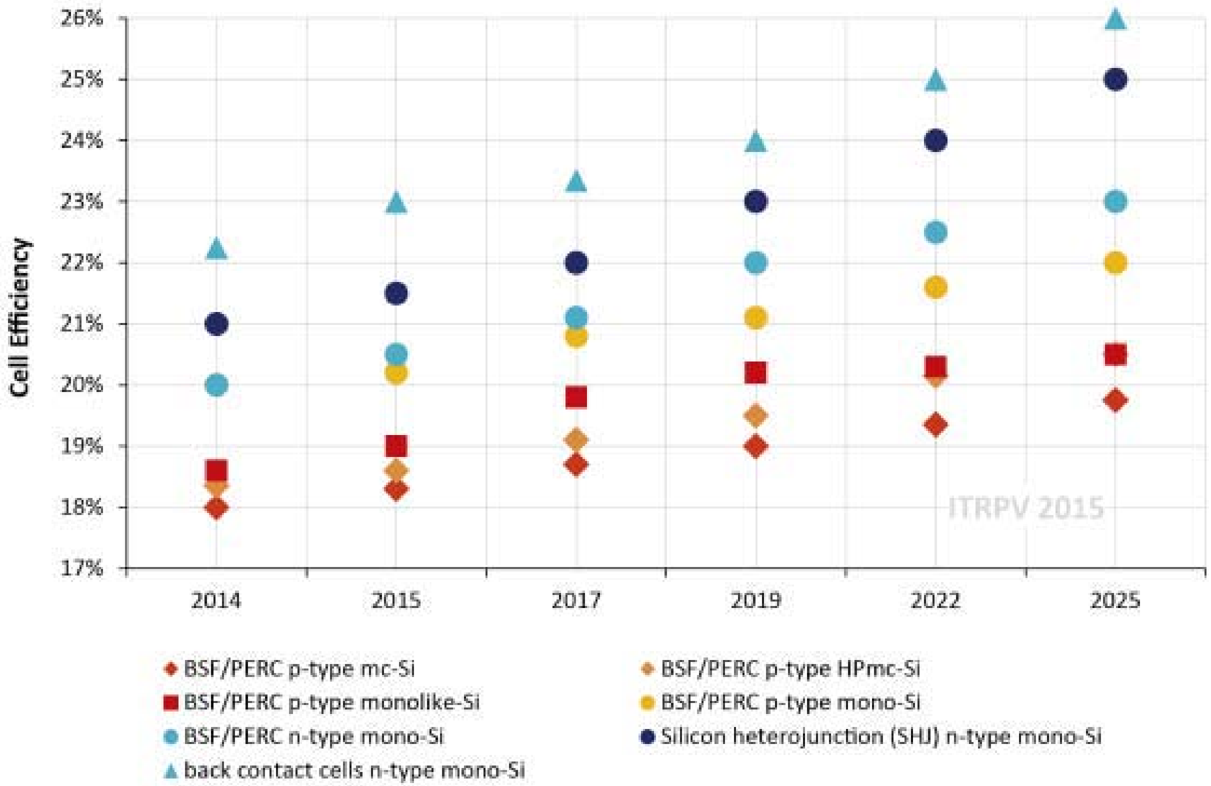
11 October2016

Content

- PV evolution according to ITRPV
- From Cell to Module
- ECN developments foil based back-contact cells and module technologies
  - Thin cells
  - Cost reduction of module materials
  - Outdoor test data
  - *MWT-HJ cells and implications for modules*
  - View towards applications
- Summary and Outlook

From standard to High η Si cell concepts

- From p- to n-type front to back contacted   (PERT, HJ)
- From front to back contact to back contact (MWT,IBC)
- From monofacial to bifacial (> kWh/kWp)



ITRPV 2015: Average stabilized efficiency values for Si solar cells (156x156mm²).

N mono IBC

N mono HJ

N mono PERC

P mono PERC

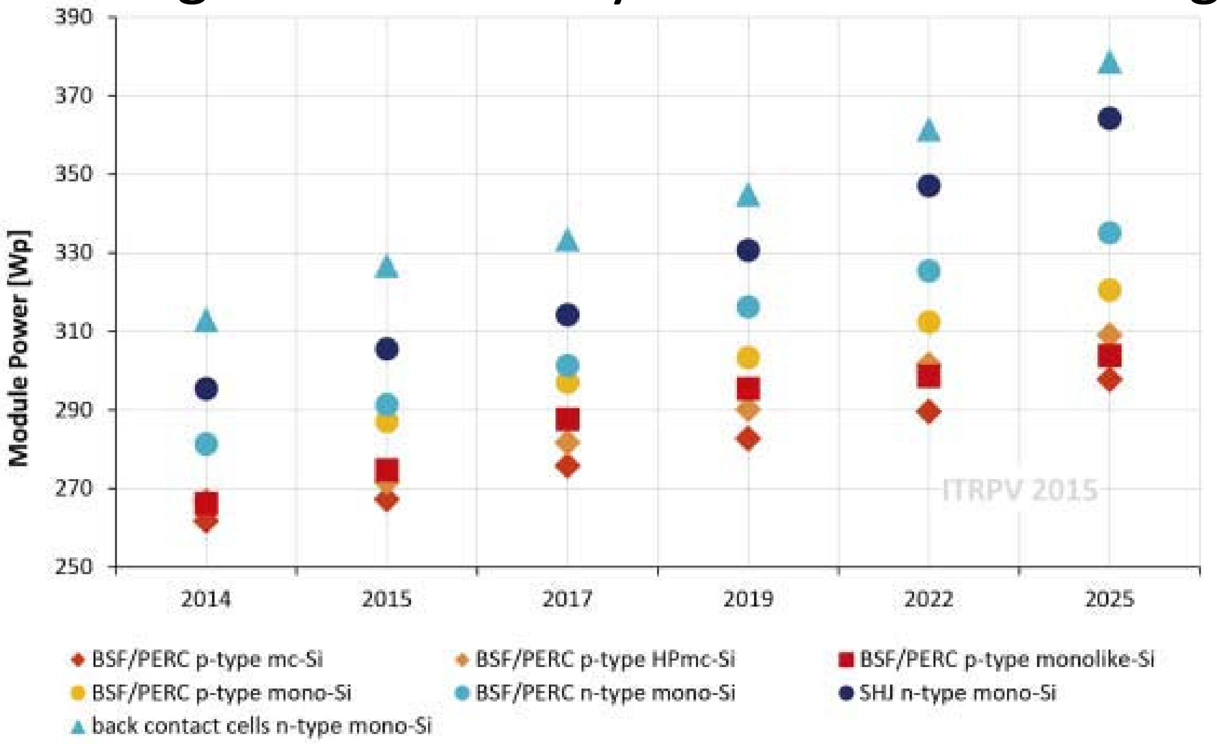
P monolike PERC

P multi PERC

ITRPV roadmap 2015

To be translated to High Power modules

- Products: 60 cells 156 mm
- Optimize CtM
- Low cost without sacrificing quality and reliability
- Long term reliability is crucial for stable growth



ITRPV roadmap 2015

ITRPV 2015: Predicted trend curve for module power for different c-Si cell types.

Expected market shares

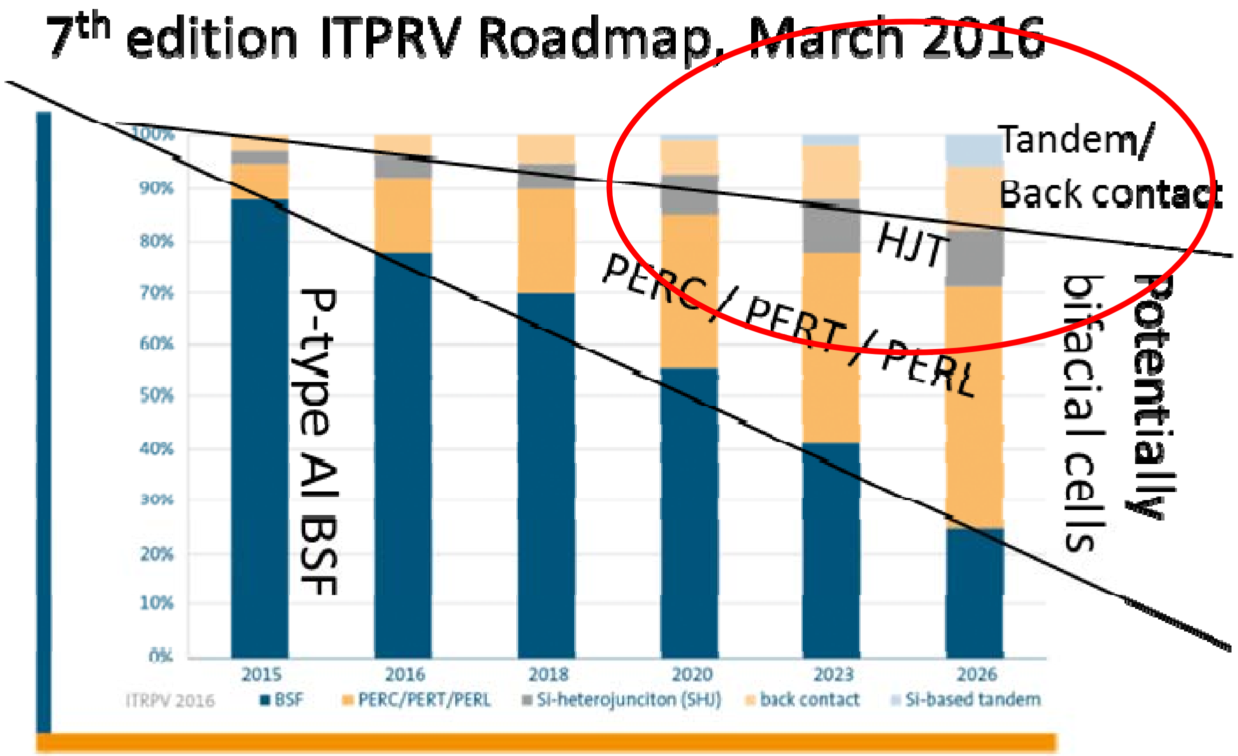


Fig. 33: Worldwide market shares for different cell technologies.

Trends according to ITRPV roadmap:

- PERC concepts will become mainstream
- **Back Contact and HJ concepts expected to increase for niche markets**

How to adapt the module technology so that it fits with a specific cell concept

Each cell concept has to be individually evaluated for the best module concept in terms of:

- Long term stability → >30 years product lifetime
- Lowest cell to module losses → CtM value
- Optimized production costs → high yields, low investment costs
- Optimized Bill of Materials (BoM)
- Best energy yield → temperature, low light, incident angle, shadow…

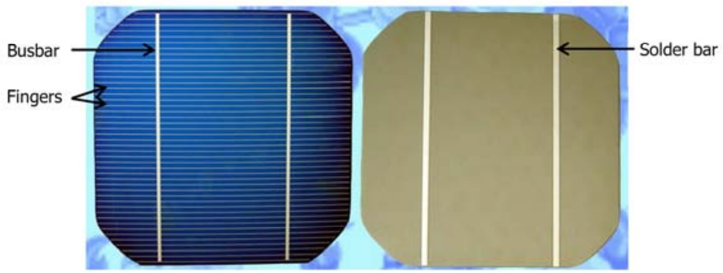
There are special requirements for individual concepts, a.o.

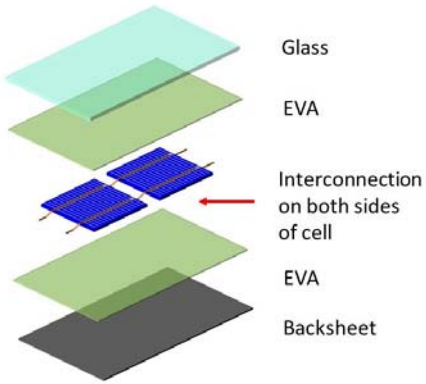
- IBC: soldering not trivial
- SHJ: low Temperature interconnection, barrier for moisture ingress
- Etc…

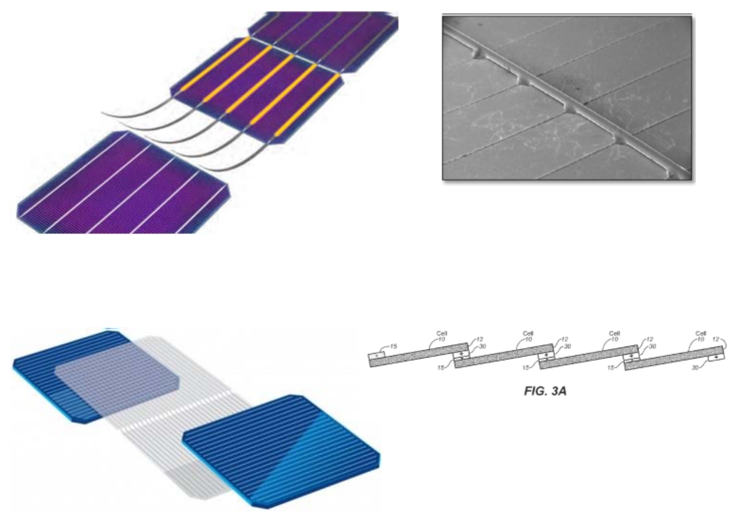
Schneider, ISC, Tokyo, 2013

From cell to module….
different approaches

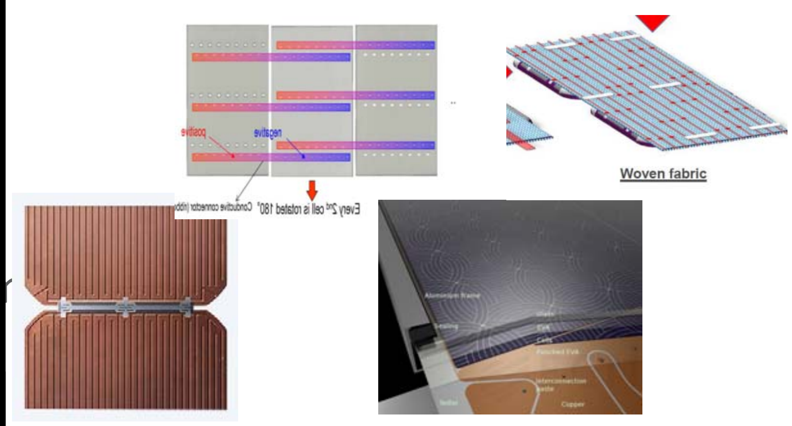
- Standard







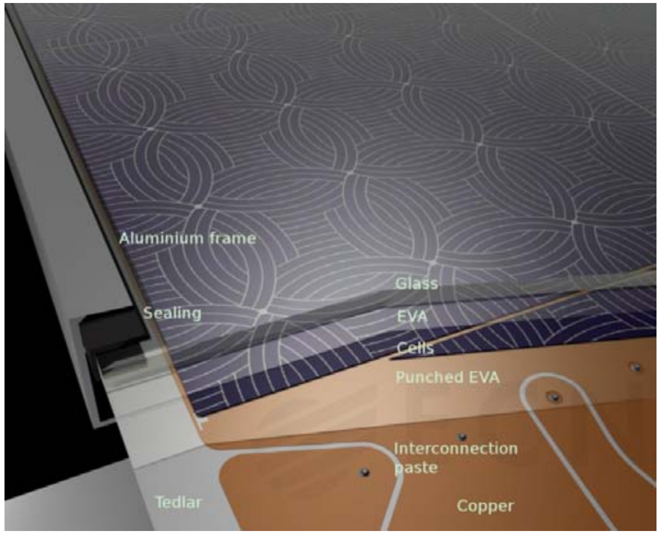
- Front to rear contact (Perc, HJ)
  - Move to more busbars: 2,3,4,5
  - No Busbars: Multiwire/smartwire (Schmid, MB)
  - Shingling, cascading (Sunpower, Silevo)
- Back Contact (MWT, IBC)
  - Rear soldering (tabbing, woven fabrics, MW) (ISE, in
  - Smart tab edge interconnection (Sunpower)
  - **Foil interconnection technology (ECN, Eurotron,..)**

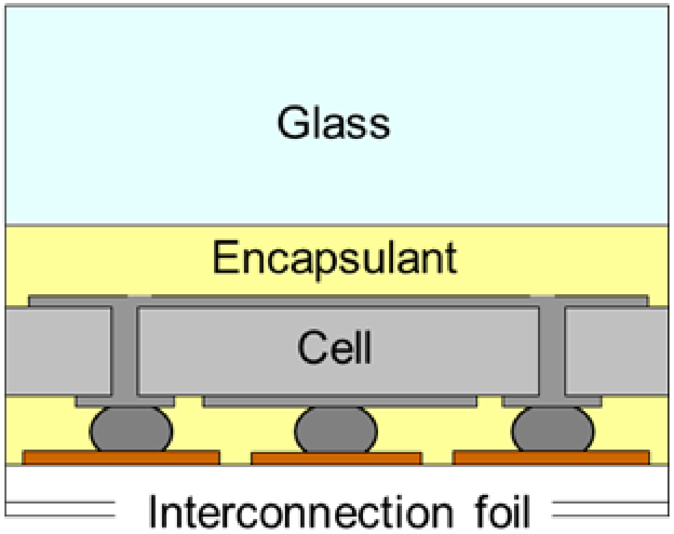


Cell to module: Back Contact

MWT, IBC: foil

- Conductive back-sheet foil
  - Copper as conductive layer
  - Patterning by chemical etching or milling
- Contact cell to foil through conductive adhesive
  - Printed on foil
- Isolation cell from foil by encapsulant
  - Holes at contacts





Cell to module: Back Contact

- Reliability proven
  - IEC certification achieved
- Production equipment developed by Eurotron: high level of automisation
  - >300 Wp nMWT certified
  - >280 Wp IBC (120 micron cells, special BoM design for recycling)

EUROTRON
POWERFUL INSTRUMENTS

CERTIFICATE

No. Z2 10 06 74154 001

Holder of Certificate: Energy research Centre of the Netherland
Westerduinweg 3
1755 LE PETTEN
THE NETHERLANDS

Production Facility(ies): 74154

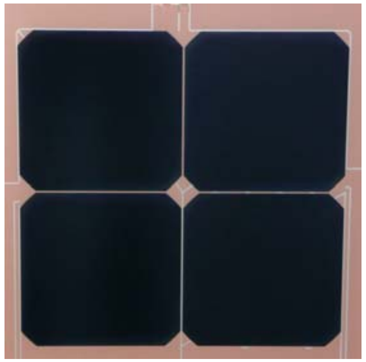
Certification Mark:

Product: Crystalline Silicon Terrestrial Photovoltaic (PV) Modules

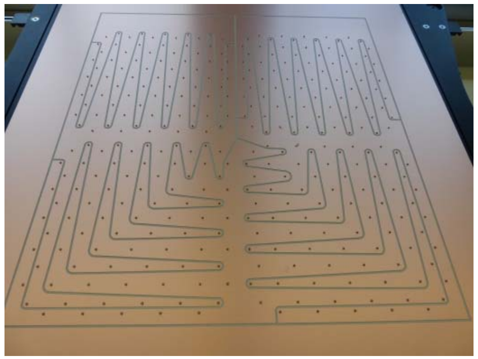
Back Contact Module R&D at ECN

- BoM testing in mini pilot module line: 4 cells modules as scale model for large area module
  - Integration of (thin) BC cells from ECN cell baselines or other sources
  - Comparison of module materials and new processes
  - CtM power optimization by optical and electrical engineering
  - Reliability , outdoor testing
  - Special prototypes

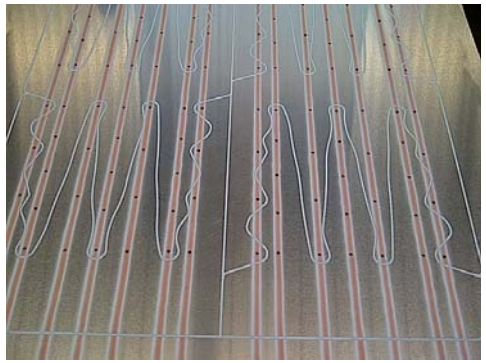
6 via MWT



All black IBC



Cu CBS



Cu Coldspray on Al CBS

Cell-to-module change

- A paper is published in PV-International this month on CtM changes specifically for back-contact module technology

Positive cell-to-module change: Getting more power out of back-contact modules

Fab & Facilities
Materials
Cell Processing
Thin Film
PV Modules
Market Watch

Bas B. van Aken & **Lenneke H. Slooff-Hoek**, ECN – Solar Energy, Petten, The Netherlands

ABSTRACT

Cell-to-module (CtM) loss is the loss in power when a number of cells are interconnected and laminated in the creation of a PV module. These losses can be differentiated into *optical losses*, leading to a lower photogenerated current, and *resistive losses*, leading to a decrease in fill factor. However, since the application of anti-reflection (AR) coatings and other optical 'tricks' can sometimes increase the I_{sc} of the module with respect to the average cell I_{sc}, the CtM loss in such cases needs to be expressed as a negative value, which gives rise to confusion. It is proposed to use the CtM change, where a negative value corresponds to a loss in current or power, and a positive value to a gain. In this paper, the CtM changes for back-contact modules utilizing a conductive foil are described and compared with other mature module technologies. A detailed analysis of the CtM change for a full-size metal-wrap-through (MWT) module is presented.

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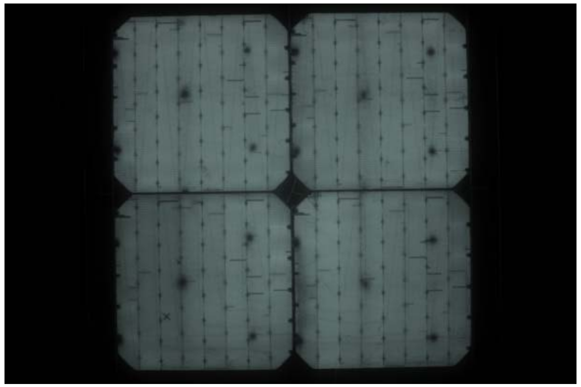
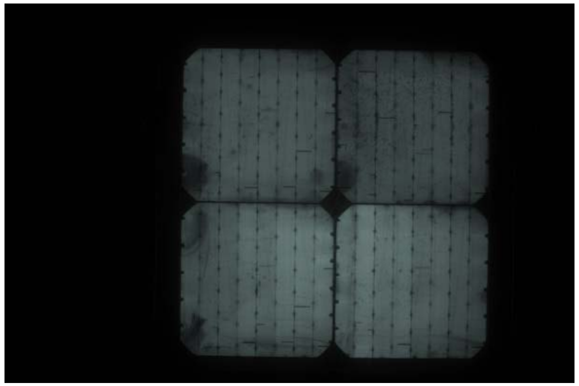
< **€ / m²**

Handling of thin cells

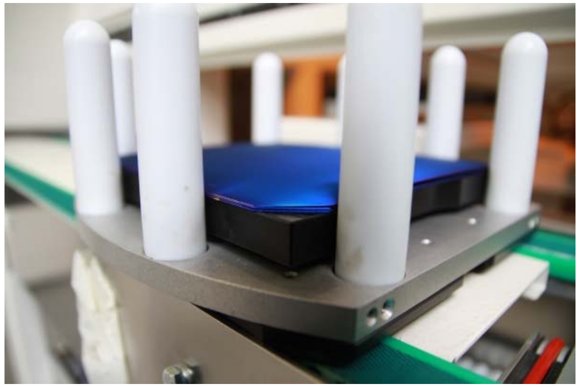
- IBC cells down to 80 micron cells with adapted processing
- 4 cells mini modules have been fabricated: no breakage/cracks and FF > 74 %
- Cell handling down to 80 micron proven with industrial module equipment (Eurotron)



100 micron



80 micron

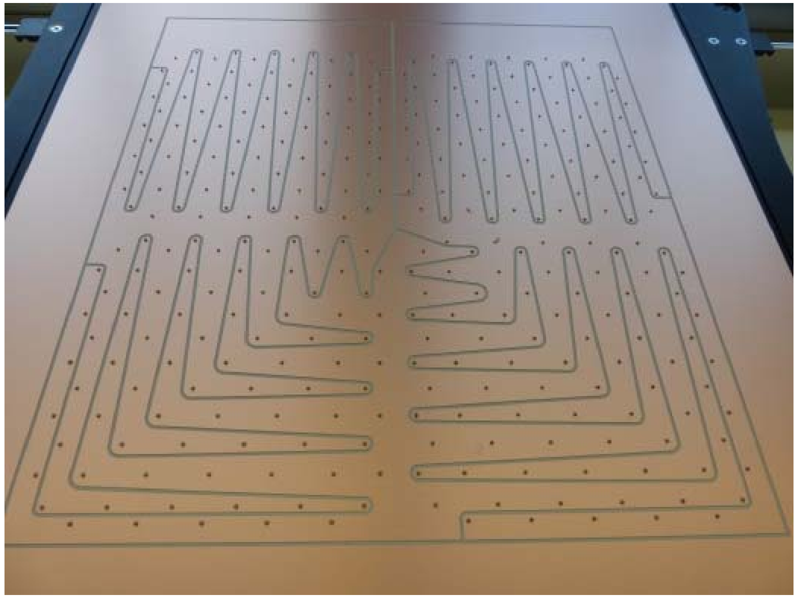


Automated handling with industrial equipment

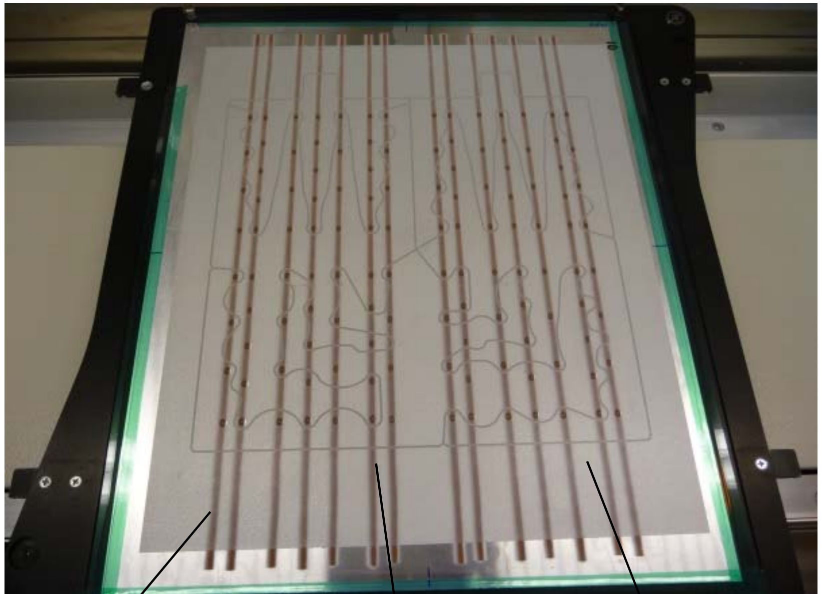
< € / m²

Reduction cost conductive back-sheet foil

- Replacing copper by aluminium
- Local application of Copper powder by Cold-Spray on Al foil
- Conductive adhesive printed on the Copper pads: < 1 mOhm Rc
- Potential cost saving ~3 Euro per full size backsheet



Goris et al. EUPVSEC 2016

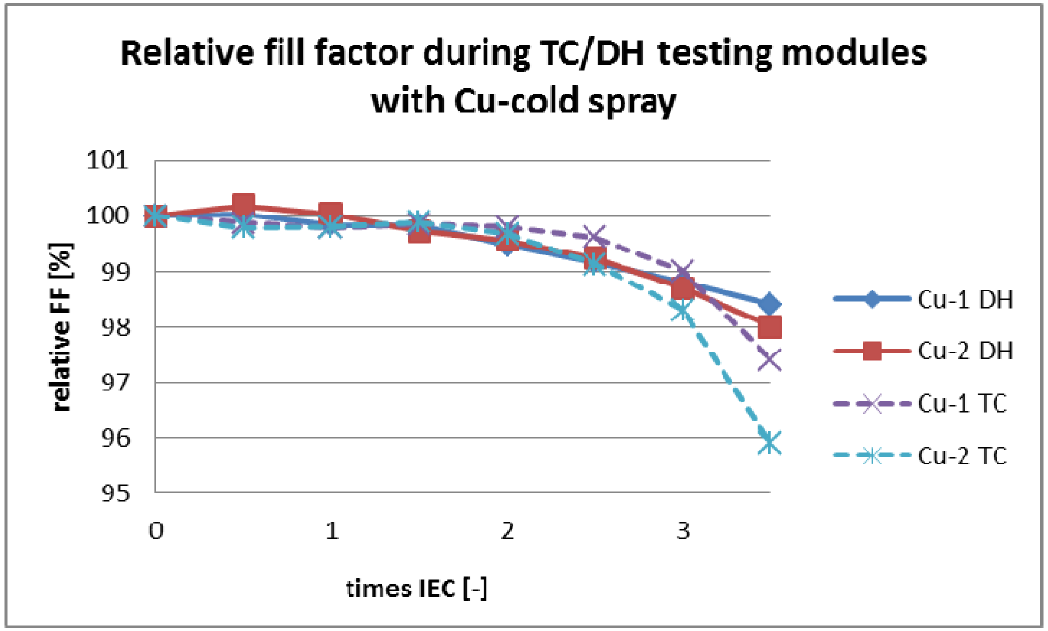


< € / m²

Reduction cost conductive back-sheet foil

Performance MWT and IBC modules

Module	FF [%]
MWT on Cu	75.9
MWT on Al + CuCS	75.9
IBC on Cu	74.9
IBC on Al + CuCS	74.9



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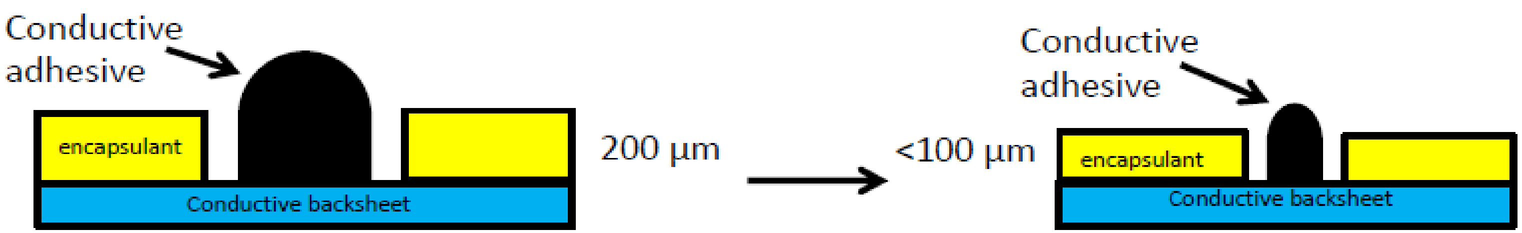
MWT Modules passed 3.5 x IEC test!
Similar trends observed for IBC after 1 x IEC

< € / m²

Reduction cost conductive adhesive

- Reduction silver content from >80% to <20%
- Reduction volume by using thinner encapsulants→ **Powder coating**
- More contact points possible without cost penalty



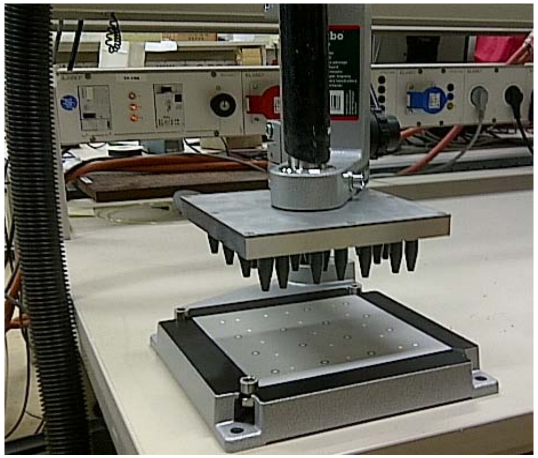
< € / m²

Reduction cost conductive adhesive

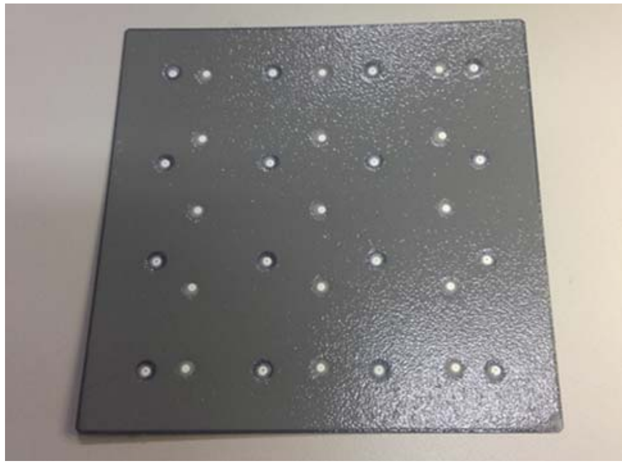
Powder coating process

- Electrostatic deposition technique
- Large freedom to tune layer thickness
- Applied on solar cells and glass
- Cleaning contact pads (punching is eliminated)

Spray booth and controller



Contact point cleaner



Coated cell and clean contact points

< € / m²

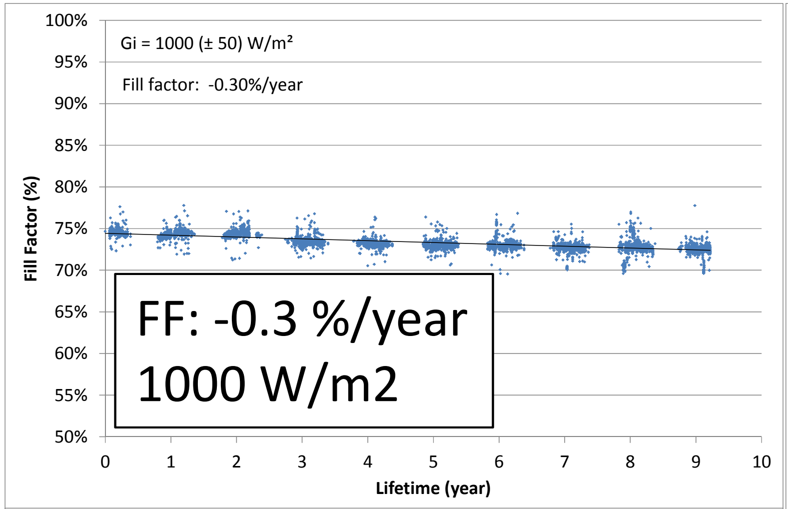
Reduction cost conductive adhesive

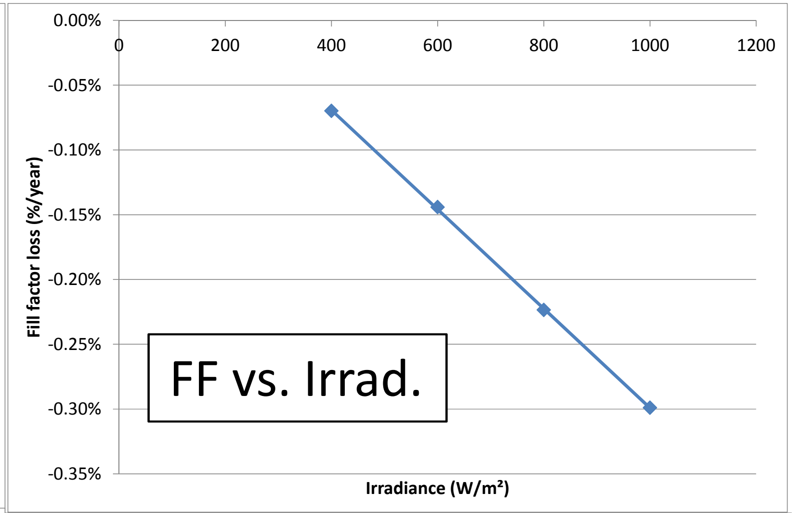
- MWT modules with Thermoplastic powder coated encapsulant on solar cell and glass: process proven for 150-200micron

Encapsulant	Isc (A)	Voc (V)	FF (%)	Pm(W)
Powder coat	8.81	2.52	75.9	16.82
EVA ref	8.75	2.52	75.9	16.66

- Challenge:
  - Find right materials that with stand IEC testing
  - Proof mechanical stability

Outdoor performance p-MWT module (2007-2016)



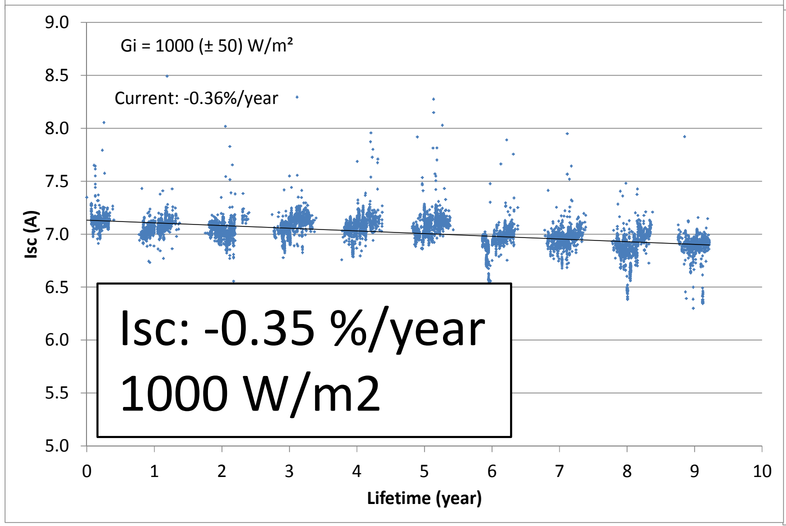


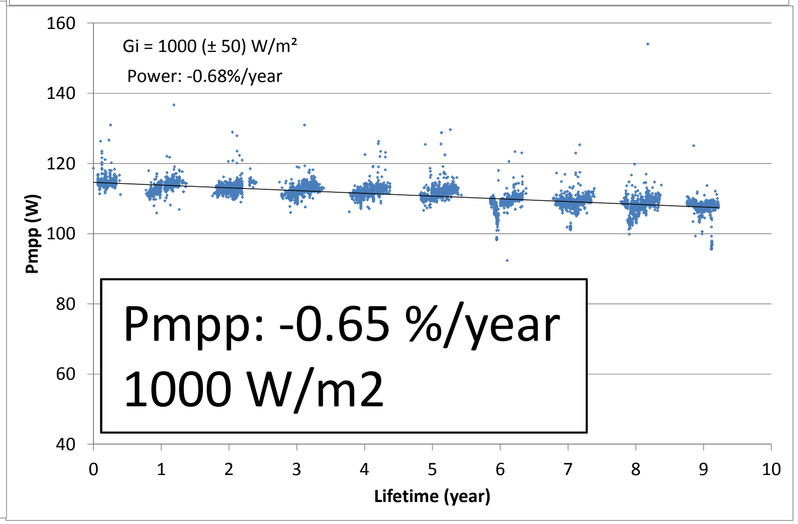
FF loss

- Electrical losses

Isc loss:

- No module cleaning

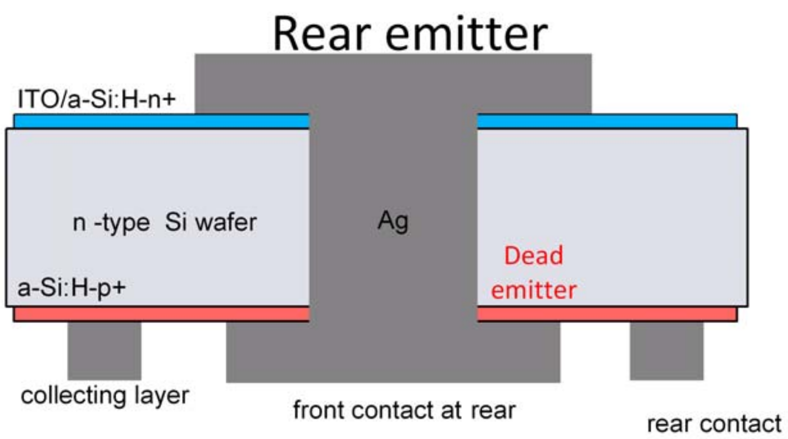


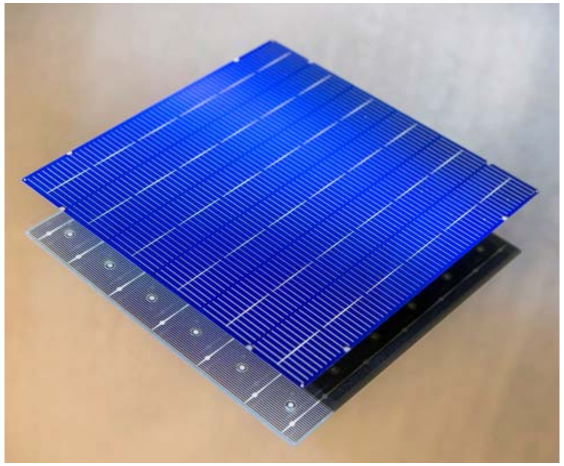


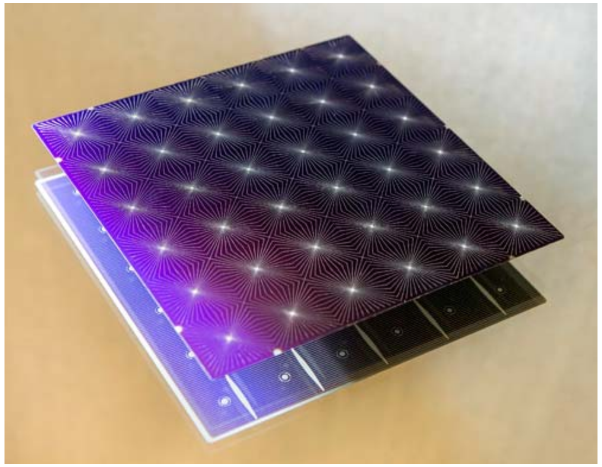
> **Wp / m²**

Performance improvements? Back to cells……

- MWT-SHJ combines advantages of silicon heterojunction (SHJ) and metal wrap through (MWT) technologies in one device:
  - SHJ shows record Voc and has a low temperature coefficient for higher module energy yield
  - MWT shows Ag cost reduction and less shading in a module
  - Module technology meet low T requirements by soldering-free







> **Wp / m²**

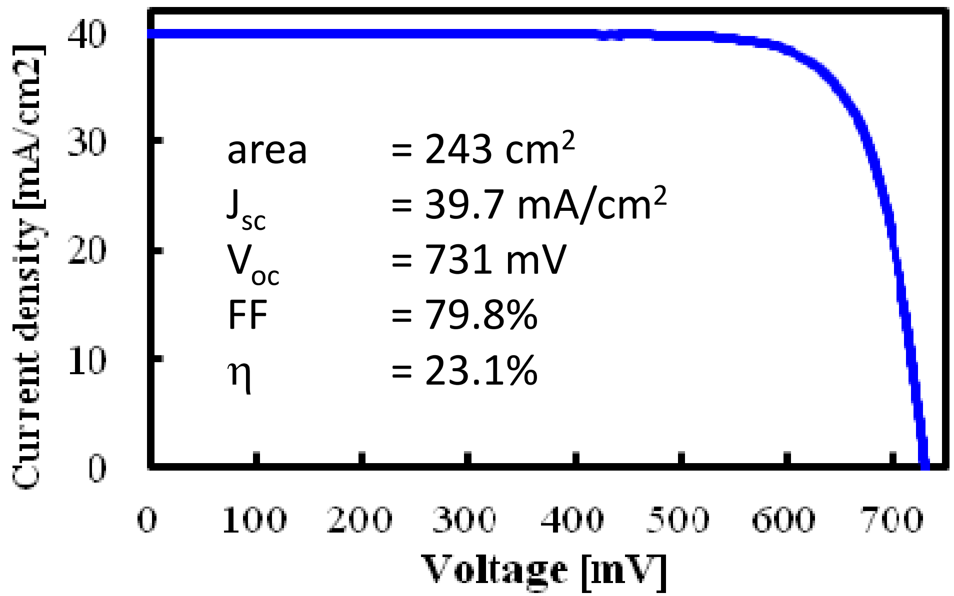
Results MWT-HJ cells

- Front side metallization improvements

From low T Ag to

Structure	Front metal	J_{sc} [mA/cm²] (shading)	V_{oc} [mV]	FF [%]	η [%]
H-pattern	Ag 3BB*	38.9 (5.6%)	722	77.3	21.7
MWT 4x4	Ag	39.1 (3.7%)	726	76.6	21.7
MWT 6x6	Ag	39.2 (3.4%)	723	77.6	22.0
MWT 6x6	Ag	39.3	719	80.0	22.6

Cu-plated, 6 x 6 vias
(*developed at CIC*)

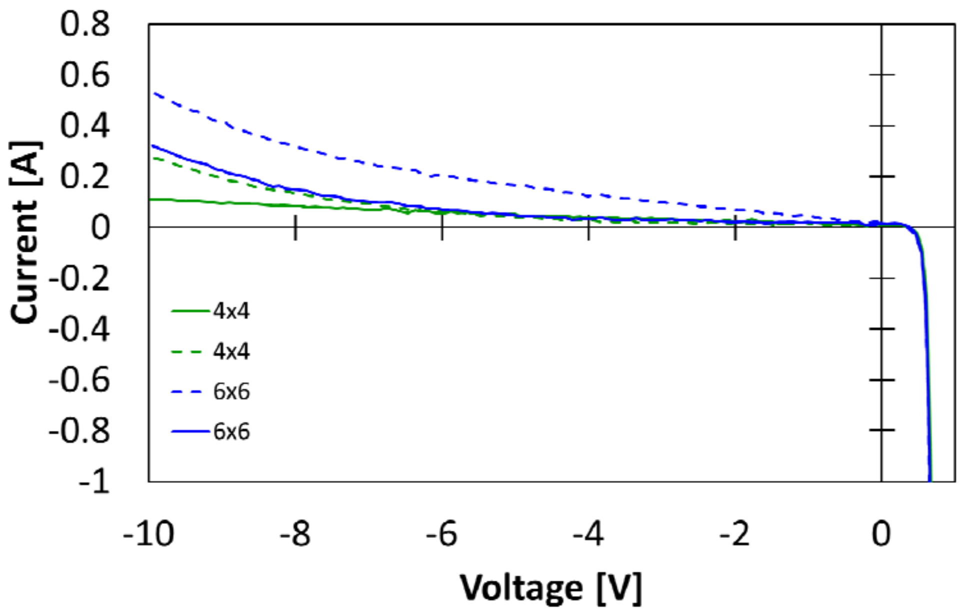


Coletti, EUPVSEC proc. 2016
Ishimura, EUPVSEC proc. 2016

> Wp / m²

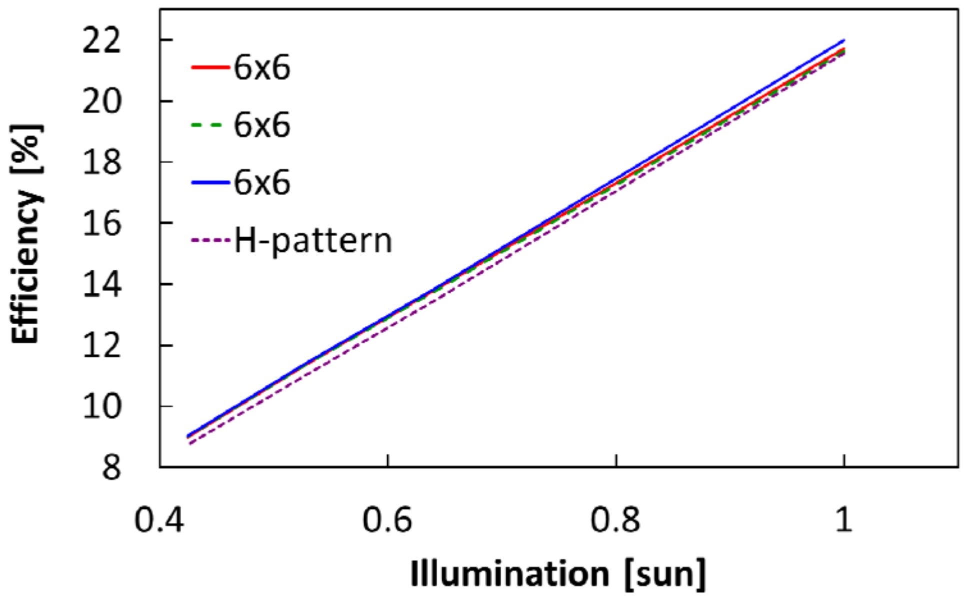
Results MWT-HJ cells

Reverse characteristics



I rev < 0.5 A at -10 V for 4 x 4 and 6 x 6

Sensitivity towards illumination



Shunt and recombination behavior comparable to H pattern SHJ

ECN

From MWT HJ cell to module.....

Concept is ideally suited for conductive back sheet module technology as is IBC HJ

- Low Temperature interconnection
- Solder free

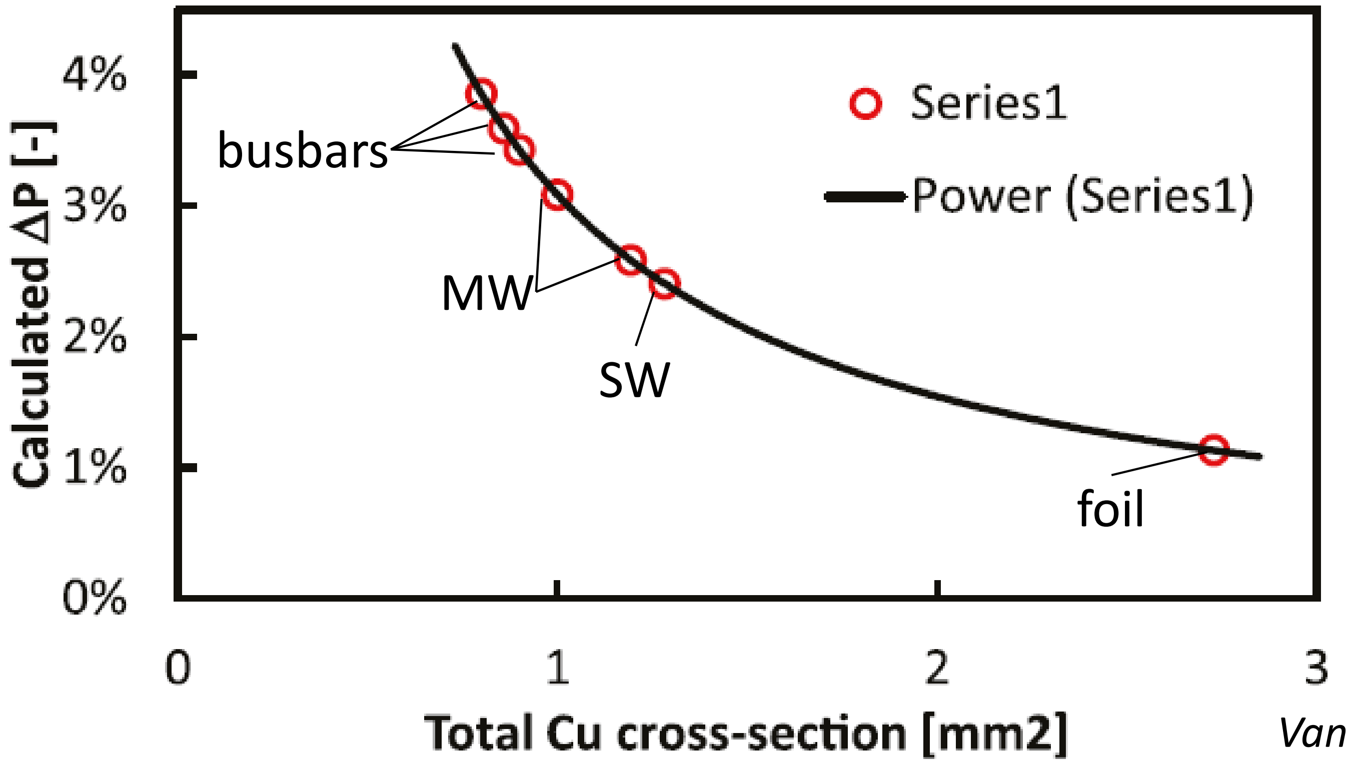
Challenges for glass / polymer back sheet modules

- Optimize CtM:
  - First trials with single cell laminates (next slides)
- Reliability: change and optimize BoM to cope with increased sensitivity towards moisture
  - Work in progress

From MWT HJ cell to module.....

CtM change of the fill factor for various interconnection schemes

- Only resistive losses in interconnection material: tabs, wires, foil
- the calculated power loss is inversely proportional to resistance and thus to the total cross-section of the interconnection material



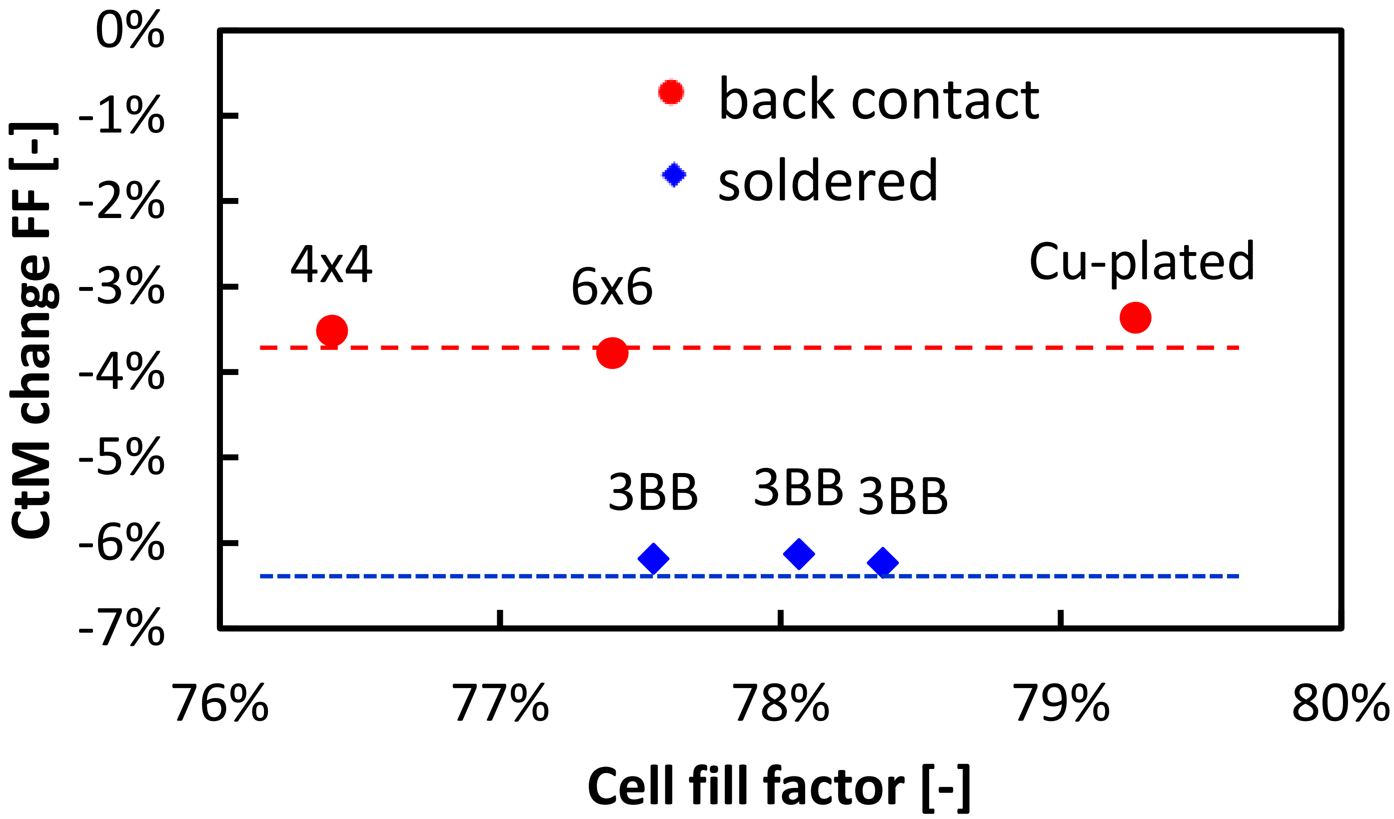
Van Aken, PV international October, 2016

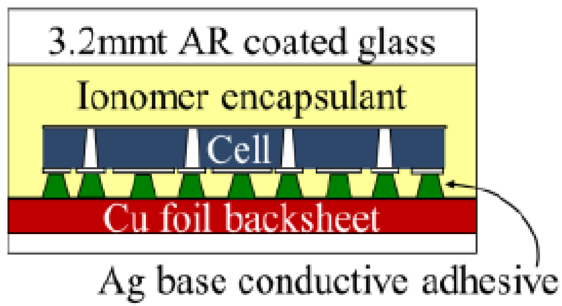
> Wp / m^2

From MWT HJ cell to module.....

CtM change for soldered and back contact single cell laminates

- Electrical layout not optimized: explains larger CtM change
- Relative improvement CtM change BC vs. Soldered



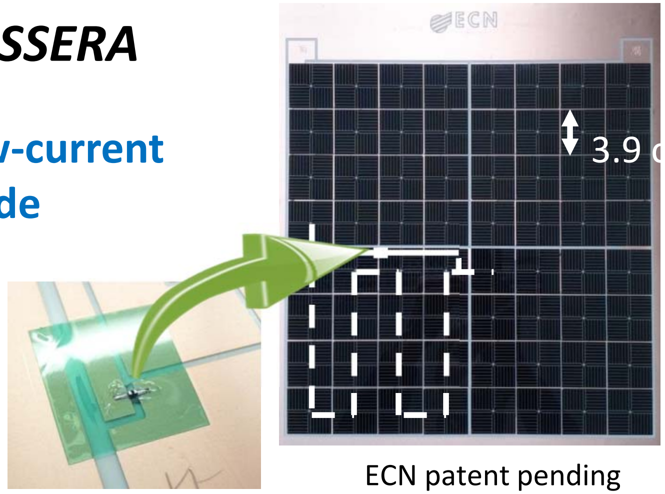


View towards applications

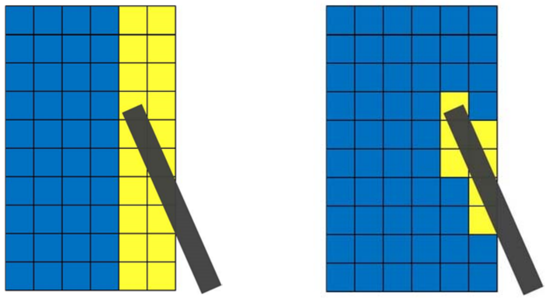
- Broaden applicability: Focus on systems and applications in BIPV
  - **aesthetics, uniform appearance** **size flexibility, shade tolerance** **freedom of design**

TESSERA

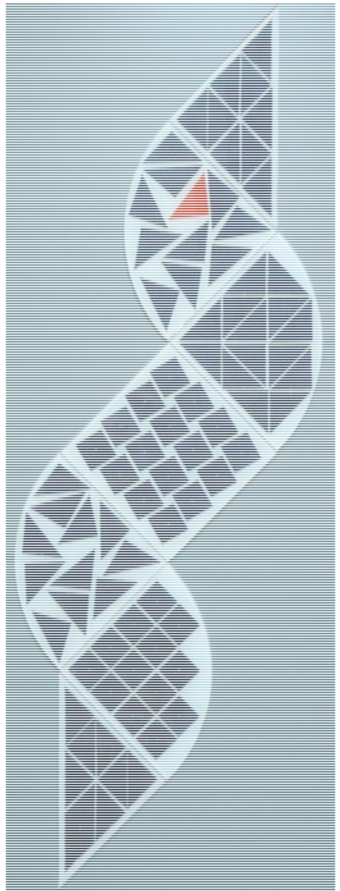
Low-current diode



ECN patent pending



Eurotron, Heliox, Stafier



Summary & Outlook

- All different HE solar cell concepts can be translated to a specific module concept and fullfill all the demands: highest yield , lifetime , low costs,.. there is not one module concept that fits all cell concepts

- Market adoption of new cell and module concepts is not straightforward
  - Incremental improvements preferred
  - Bankability: lack of long term field experience data
- How to accelerate market uptake?
  - Show **competitiveness** by significant performance improvements, cost reduction approaches and field data collection!!
  - Broaden applicability BIPV: Aesthetics, transparency, colours, flexibility of shape & size, etc, I2PV: Bifaciality

Acknowledgements

- MWT – HJ cells/modules

Gianluca Coletti (Coletti@ecn.nl)
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- Cold spray and powder coating

Maurice Goris (goris@ecn.nl)
Benjamin Kikkert

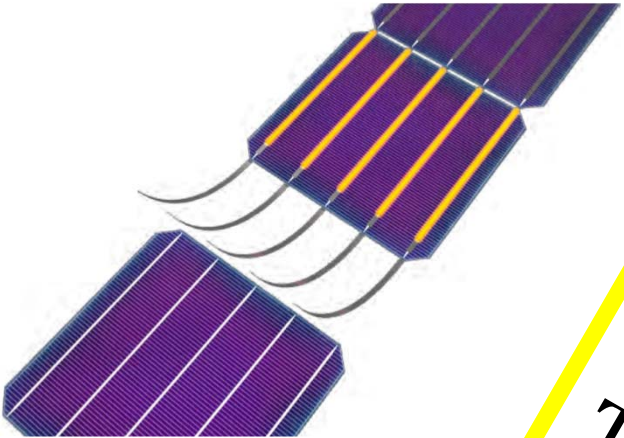
- Thin cell modules

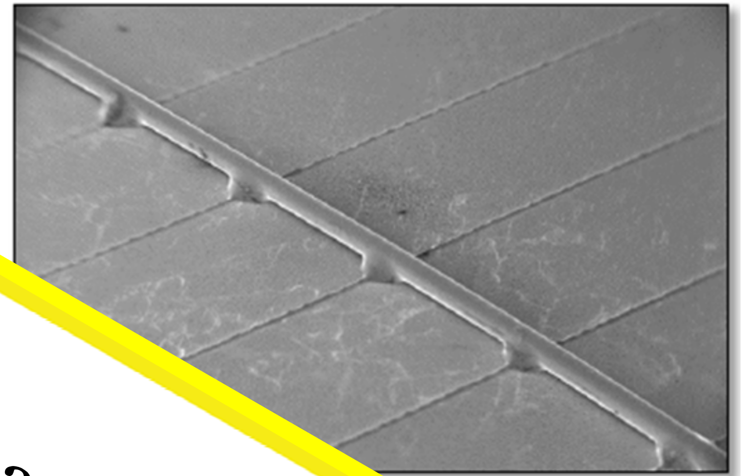
Paul Sommeling
Lars Okel

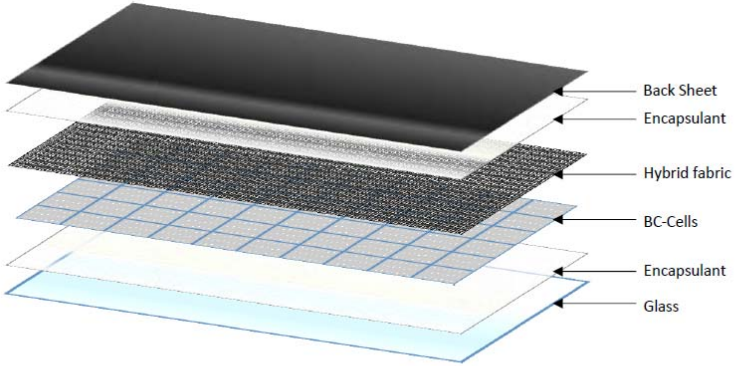
And all other colleagues that contributed for many years on this development

TKI Urban Energy

EC-FP7







Thank you for your attention