

DSM Advanced Layers for Bi-facial Modules

MILICA MRCARICA
Bi-facial workshop Konstanz , 25th Oct 2017

Outline

- DSM Advanced Solar at a glance
- DSM Light Trapping Film (LTF) and ARC for bifacial modules
- LTF application development
- Indoor and outdoor testing
- Enhancing performance with LTF
- Conclusions
- Outlook

Growth driven by global megatrends

Health & Wellness



Aging population

Healthcare issues

Food composition

Health

Global Shifts



Population growth

Urbanization drive

Wealth increase

Nutrition

Climate & Energy



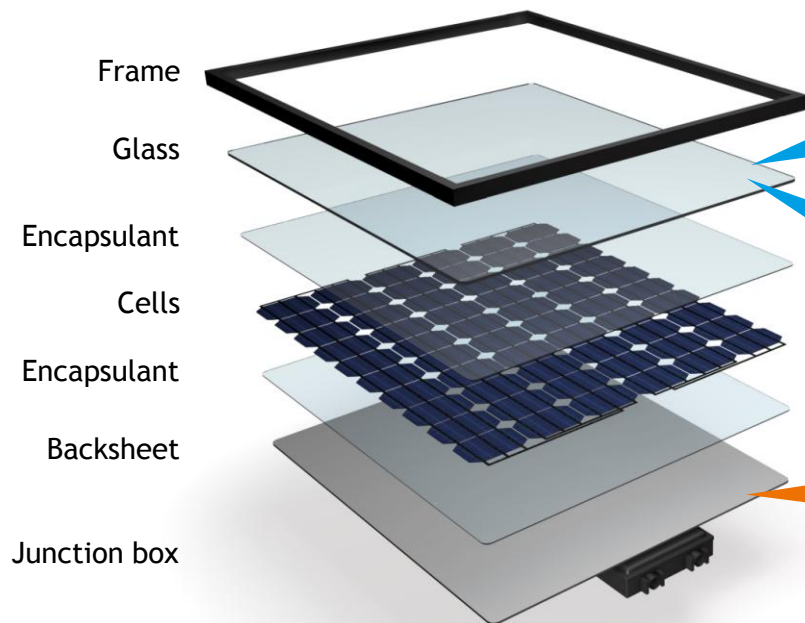
Sustainability concerns

Resources constraints

Energy concerns

Materials

DSM solutions are lowering the cost of solar power



DSM Anti-Reflective coating

Delivers a 3% higher power output consistently in flash tests compared to uncoated cover glass

DSM Anti-Soiling coating

Increasing IRR of solar projects, by increasing power output and lower maintenance costs

DSM Endurance Backsheets

Reliable solar performance in extreme environments

Advanced Solar in one view

Global presence

- Two production sites (Europe & China)
- Two R&D and Application Development centers (Europe, China)
- Five sales offices (Europe, China, US, India, Japan)

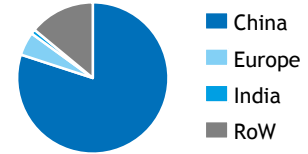


Products

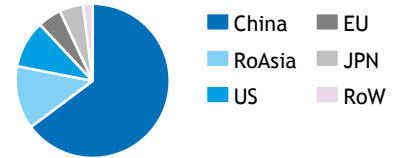
- Anti-reflective coating - global market leadership
- Endurance backsheet - launched 1Q16
- Anti-Soiling coating - launched 2Q17
- Strong innovation pipeline

Markets by region | 2016

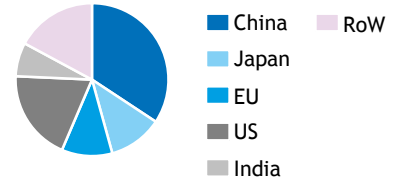
PV Glass Manufacturers (AR coating)



PV module Manufacturers (Backsheet)

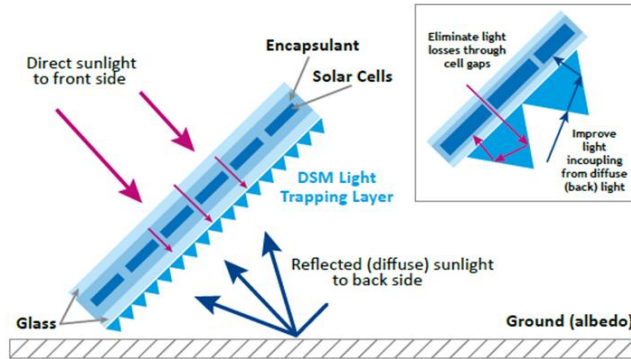


PV system Installation (end-market)

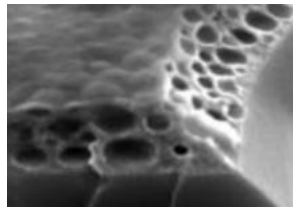


DSM Light Trapping Film (LTF) and ARC for Bifacial Modules

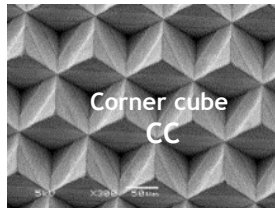
Development path



Proposed bifacial module optical layers :
 ARC front / LTF rear : high reflective rear side
 for light coming from the front, enhanced
 capturing of diffuse light coming from the back



Front glass DSM ARC



Rear glass DSM LTF

Screening STC test with 4 cells bifacial module

Bifacial module indoor and outdoor testing protocol

Bifacial module optimal optical layers : ARC /LTF

Adopted benchmarking ARC/LTF against ARC/ARC

Modelling of LTF benefits in BiFi modules and
 demonstration of improved LTF+ structure

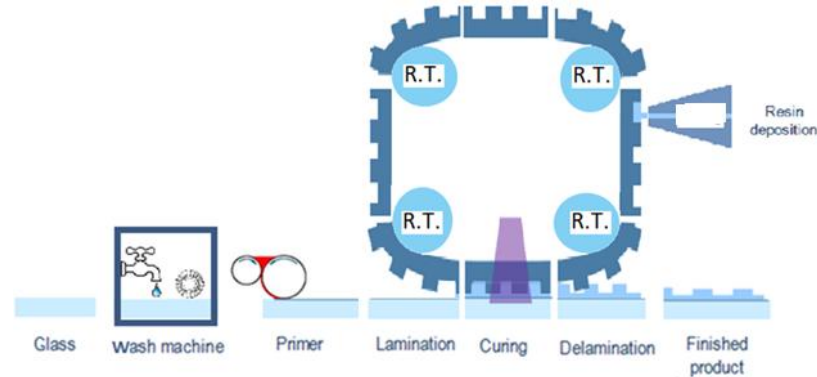
Developed LTF material application method ready for
 scale -up

Performed IEC material testing

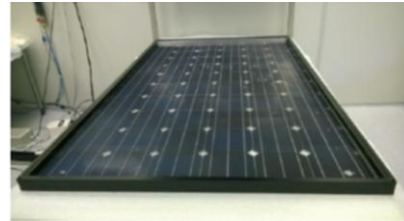
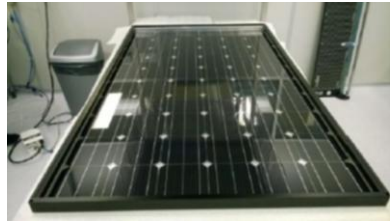
Identified and quantified soiling level

6 Roll to Sheet (RtS) Tech Package Status

Tech package for inline industrial process is ready:



- Primer solution and Resin formulation is set
- Resin application on the master film to reach higher speed
- Parameters established to apply a homogenous coating layer
- IEC tests passed (DH, HF, TC, UV)



Full size module before and after LTF application

LTF Indoor Performance -STC Performance

Full size 60 cells bifacial modules - 4bb Mega PERT cells

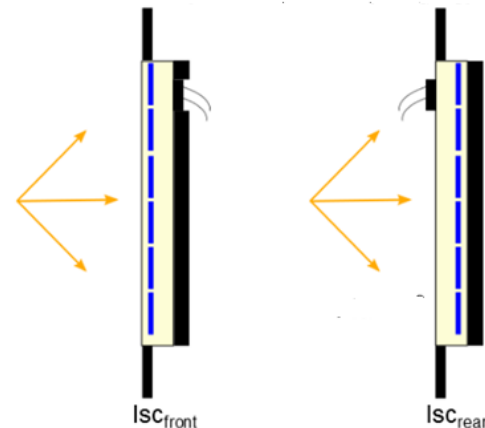
- Gain (%rel) measured on the same module after LTF rear side application vs initial bare glass

Tested Side	I_{sc} (% rel)	P_{mpp} (% rel)
Front	0.7 ± 0.2	0.5 ± 0.1
Rear	6.4 ± 0.3	6.3 ± 0.2

- Gain (%rel) ARC/ LTF vs ARC/ARC and ARC/SM Bare glass front STC test black background

STC Test Side	Front Glass	Rear Glass	I_{sc} (% rel)	P_{mpp} (% rel)
Front	ARC	ARC	0.8	0.7
	ARC	SM	0.4	0.7

- Indoor STC front IV tests : 0.7 (Rel %) or 2W gain with LTF at the rear , vs ARC at rear of bifacial module.
- There is only a small gain with ARC vs bare glass at the rear in STC tests



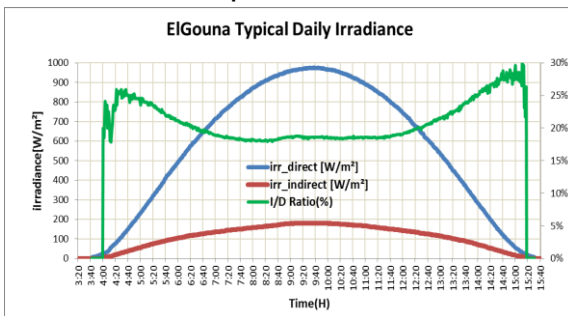
Bifacial module STC test protocol : sequential front and rear test with black background

LTF Outdoor Performance - ISC Konstanz set-up in Egypt

ARC/LTF vs. ARC/ARC Jun2 016-Nov2016

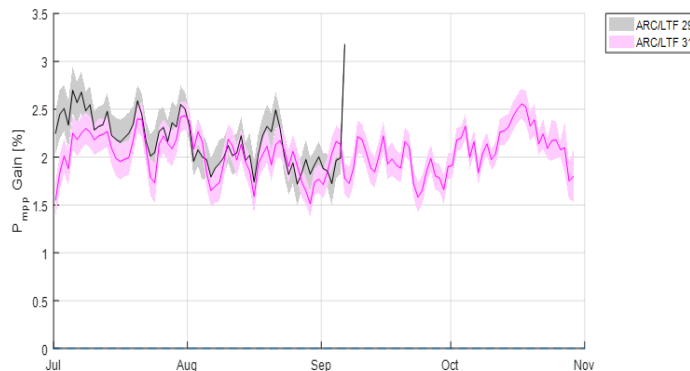


Irradiance sensors front and rear in the plane of the module



Daily Irradiation(Wh/m ²)			
Direct	Idirect	Total	Ratio I/D
6769	1323	8092	19.6%

PMPP gain



ARC/LTF Vs. ARC/ARC	Isc gain [% Rel]	Pmpp gain [% Rel]
AR/LTF 29	2.64	2.18
AR/LTF 31	2.11	2.04
AVERAGE	2.4	2.1

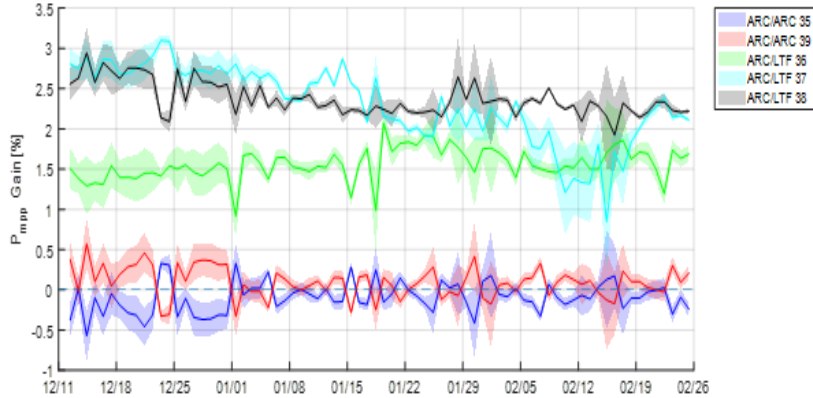
Statistical analysis with MatLab : Average total Isc and Pmpp gain (% Rel) ARC/LTF vs ARC/ARC

- Total gain includes indoor and outdoor gain
- Six full size tilted modules 4 bb Mega Cells, 3 with ARC/ARC and 3 with ARC/LTF (corner cubes), tested in pairs
- Concrete ground, ≈20% rear irradiation
- Instruments issues-high temperature & high load
- Data reliability issues & variation due to location and instruments
- Steady gain over period of 4 months
- LTF gain : 2.4% Isc; 2.1% Pmpp

LTF+ Outdoor Performance -Isc Konstanz site in Egypt

ARC/LTF+ vs. ARC/ARC Dec2016-Feb2017

PMPP gain



* Shaded area on the graph curves represents 95% confidence interval

ARC/LTF Vs. ARC/ARC	Isc gain [% Rel]	Pmpp gain [% Rel]
ARC/LTF 37	1.9	2.36
ARC/LTF 38	2.01	2.37
AVERAGE	2.0	2.4

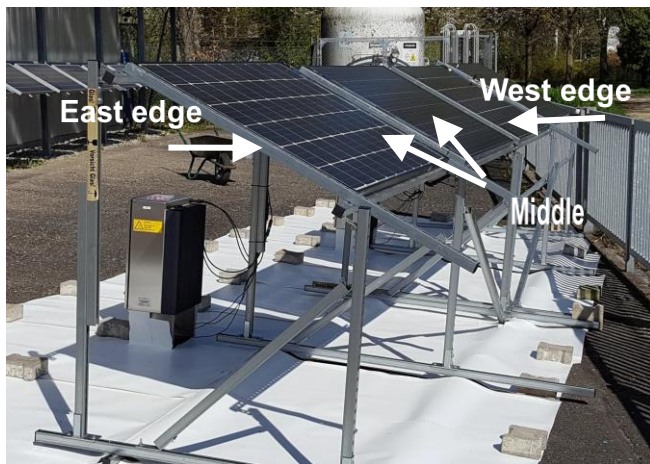
- Total gain presented : includes indoor and outdoor gain
- Five full size modules installed, 2 with AR/AR and 3 with AR/LTF+ tested in pairs
- Presented data from 22 Dec 2016 to 28 February when testing was stopped
- Instruments limitations to measure high current , Isc gain is lower then Pmpp
- Pmpp and energy gain expected to be higher without current limitations
- Observed higher Pmpp then Isc , due to lower Temp on LTF modules and thus higher voltage
- LTF+ gain : 2.0% Isc; 2.4 % Pmpp

Statistical analysis with MatLab: Average total Isc and Pmpp gain (% Rel) ARC/LTF+ vs ARC/ARC

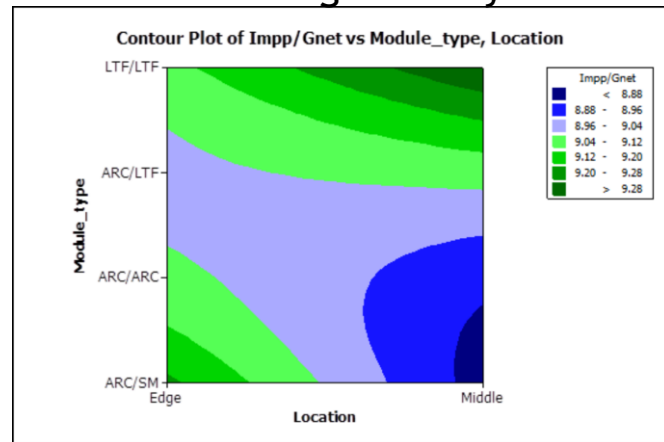
10 LTF Outdoor Performance: Set-up Konstanz

ARC/LTF+ vs ARC/SM vs. ARC/ARC +LTF+/LTF+

- 4 Tilted modules in a row
- Ground covered white
- Different self-shading level due to location
- Modules' location changed every second week



Bifacial modules test set-up at ISC Konstanz



Impp/Gnet ratio vs. location and module type : MINITAB Statistical analysis

- **Total gain presented : includes indoor and outdoor gain**
- 5 full size BiFi modules July -Sept 2016 .
- LTF at the rear decreases the effect of self shading



Stage	East Edge	Middle	Middle	West Edge	Middle Row Comparison
1 st stage: 18.07 - 31.07	ARC/LTF 9.08	ARC/SM 8.76	ARC/LTF 8.97	ARC/ARC 8.94	ARC/LTF vs. ARC/SM 2.5%
2 nd stage: 1.08 - 14.08	ARC/ARC 9.09	ARC/LTF 9.11	ARC/SM 8.86	ARC/LTF 8.95	ARC/LTF vs. ARC/SM 2.7%
3 rd stage: 15.08 - 28.08	ARC/SM 9.28	LTF/LTF 9.42	ARC/ARC 8.99	ARC/LTF 9.06	LTF/LTF vs. ARC/ARC 4.7%

Impp/Gnet (A/W/m²) for every stage and position in the row

LTF Outdoor Performance: Set-up ECN

Mid Nov 2016 - April 2017.

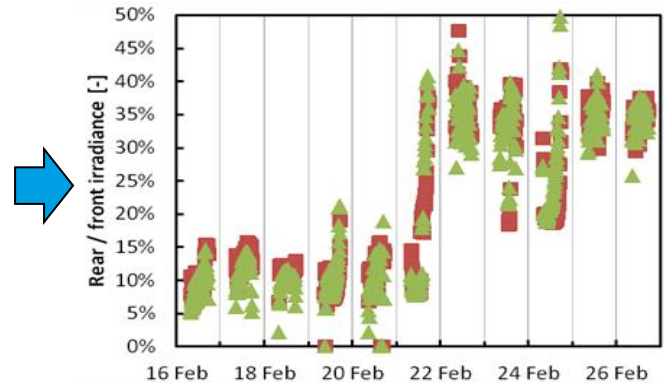
- Rooftop installed tilted modules with back shading from the rack
- Very low irradiation level at Petten and high data noise during test period
- Full size BiFi modules tested in pairs ARC/ARC vs ARC/LTF+, ARC/LTF+vs.ARC/LTF
- Grey rooftop changed to white during testing



Up to 20 February 2017



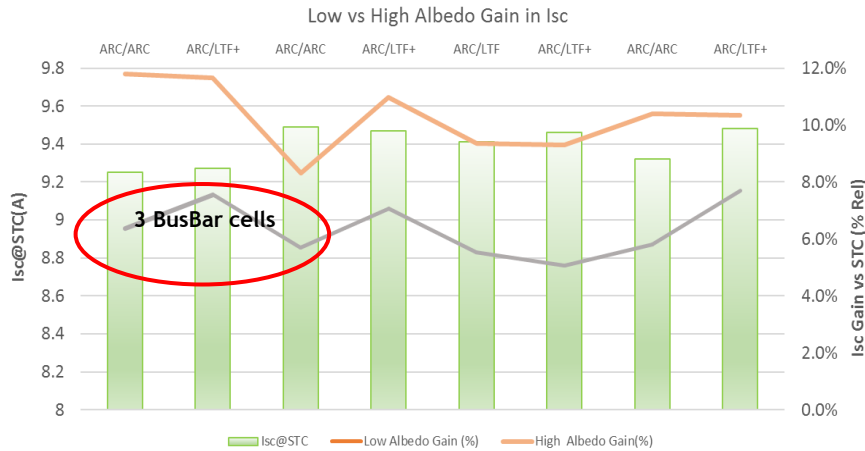
After 20 February 2017



Rear irradiance increases from 10% to 35% with white roof

Low vs. High Albedo Performance

ARC/LTF+ vs ARC/ARC, ARC/LTF+ vs ARC/LTF



Bifacial glass Layers	Low Albedo Gain (% Rel)	High Albedo Gain (% Rel)
ARC/ARC	5.7%	9.4%
ARC/LTF+	6.4%	9.8%

Average Isc gain (% Rel) vs. STC Isc value with Low and High Albedo

- Total Isc and Pmpp gain presented : includes indoor and outdoor gain
- Full size BiFi modules compared in pairs
- White roof compared with grey increases Isc gain vs Isc@STC from 6% to 10%
- No significant gain increase with high albedo
- LTF+ structure has the highest Isc gains , and shows ≈2% Pmpp and Isc gain compared to LTF - CC structure.

Isc gain (% Rel) vs. STC Isc value with Low and High Albedo

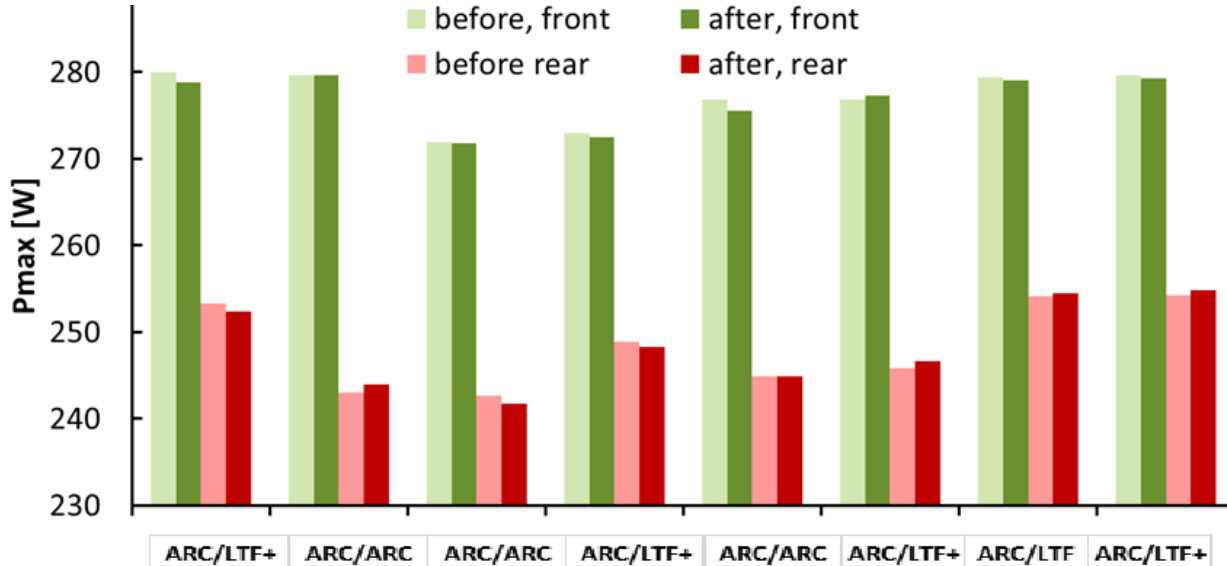
Comparison in Pairs	HIGH ALBEDO		LOW ALBEDO	
	Isc_gain (% Rel)	Pmpp_gain (% Rel)	Isc_gain (% Rel)	Pmpp_gain (% Rel)
ARC/LTF+ Vs. ARC/ARC	3.23	3.03	1.99	1.12
	1.78	2.53	2.98	2.51
AVERAGE	2.51%	2.78%	2.49%	1.82%
ARC/LTF+ Vs. ARC/LTF	1.34	1.17	2.08	1.81

Statistical analysis with MatLab : Average total Isc gain (% Rel) ARC/LTF+ vs ARC/ARC and ARC/LTF+ vs. ARC/LTF at Low and High Albedo



LTF Performance After Outdoor Exposure

Pmpp in STC test at ECN after 6 months of outdoor exposure



Pmpp after outdoor exposure is between -0.5% and +0.4% of the corresponding value before exposure, no performance change observed

Conclusions

- Indoor tests done with black background under STC conditions , demonstrated ARC/LTF vs ARC/ARC <1% Rel Pmpp gain
- Outdoor tests performed in two different climates at single module level
- There is limitation in high Imp and Isc measurement restricting the gain, need to account for instruments for higher current measurement.
- Outdoor gain of ~2.5% demonstrated for ARC/LTF versus ARC/ARC and 20% rear irradiance
- Tests with customers : 2.4% Pmpp gain with LTF and non-optimal setup
- Potential further improvements to bifacial plant setup
- Tech package for inline industrial application process is ready

Outlook : LTF and DSM Advanced Solar

- DSM is interested to find a partner who will develop and scale-up the manufacturing process, building on the technology that DSM has already developed
- If there is an interest to discuss further, please share contact information and DSM Advanced Solar business team will follow-up

Acknowledgements

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ECN: Bas van Aken



Thank you for your attention!

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