Development and testing of light weight PV modules

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2: 3S Swiss Solar Solutions AG , Schorenstrasse 39, 3645 Thun, Switzerland.

3: CSEM, PV-Center, Rue Jaquet-Droz 1, CH-2002 Neuchâtel, Switzerland

20-21 April 2023
JRC, Ispra, Italy.

The concept of lightweight PV modules

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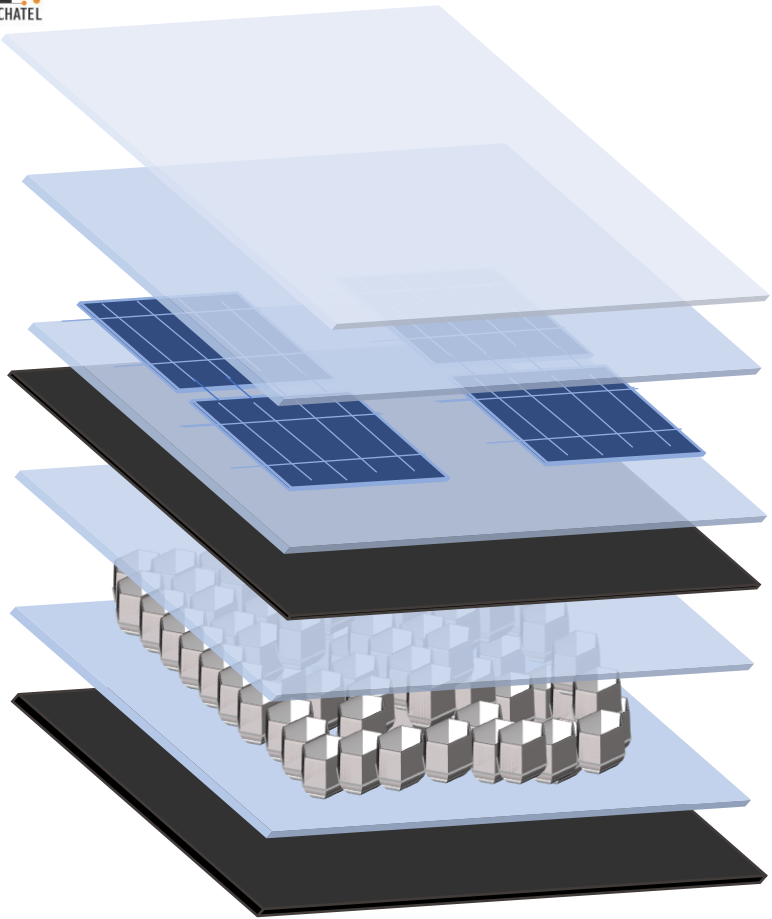

Transparent polymeric front-sheet (ETFE)

Encapsulant

Solar cells

Encapsulant

"sandwich structure"

Skin (GFRP)

Adhesion layer

Honeycomb structure (Aluminium)

Adhesion layer

Skin (GFRP)

Source: F. Lisco et al., 20th Swiss National Photovoltaic Conference, Switzerland, 2022.

Where does it stand against the conventional modules?

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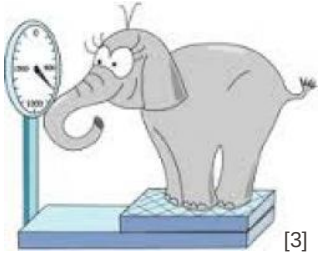
- Conventional PV modules (typically glass/backsheet): 12-16 kg/m^2
- Glass/glass modules (depending on the glass thickness): 14-20 kg/m^2 or more.



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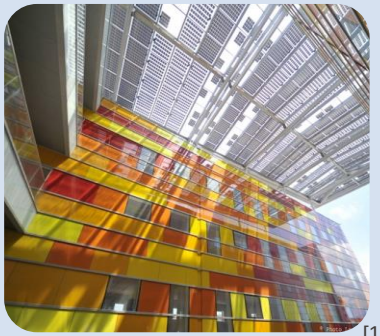
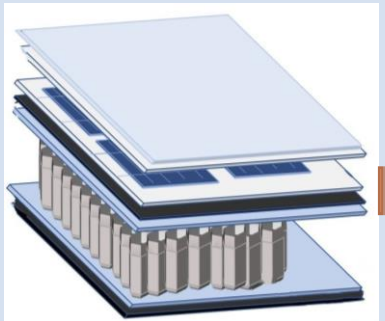


[1]



[2]

Generation -1

i. Glass/glass modules

ii. Very high weight

iii. High transportation cost

iV. Requires special attention to mounting of modules

V. high operating temperature

Generation -2

i. Composite sandwich structure to replace glass.

ii. Aluminium core

iii. Reduction of mounting structure: target a cost reduction by 50%.

iV. Reduction of weight by 50 to 75% down to 6 kg/m^2

v. Integration of colour

Challenges?

- Resistance to hail stones
- Environmental stability
- Building integration
- Fire resistance
- Aesthetics

Source: [1]: https://www.climatechangenews.com/2013/10/25/new-transparent-solar-panels-could-turn-cities-into-power-stations/, [2]: F. Lisco et al., 20th Swiss National Photovoltaic Conference, Switzerland, 2022.
[3] https://www.educationworld.com/a_lesson/04/lp338-03.shtml

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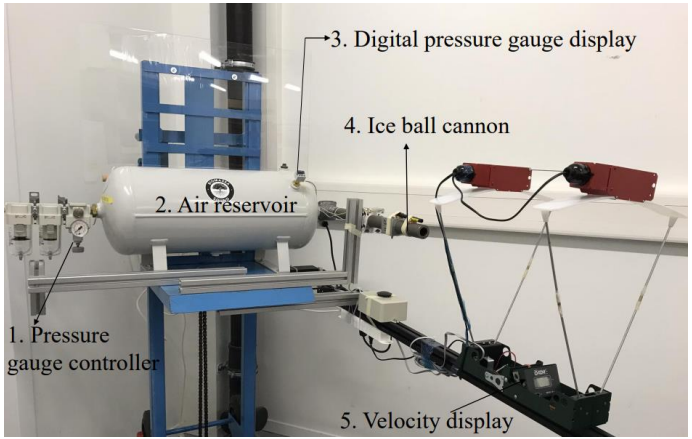
Challenges: Resistance to hail stones



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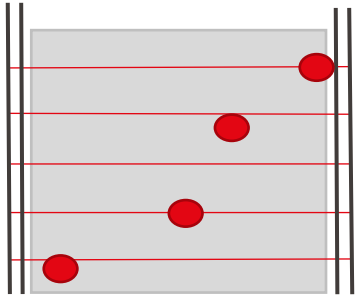
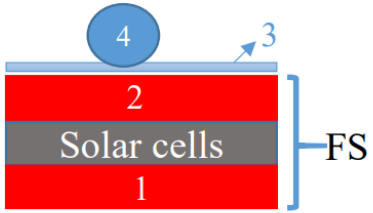
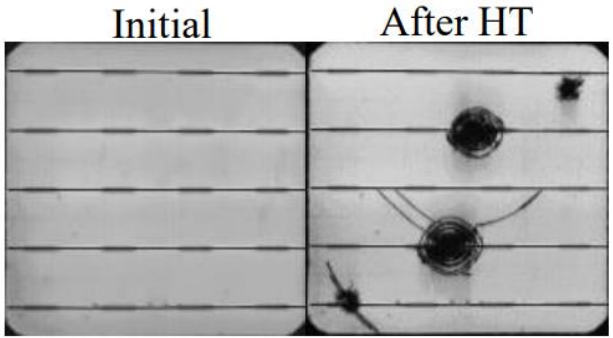






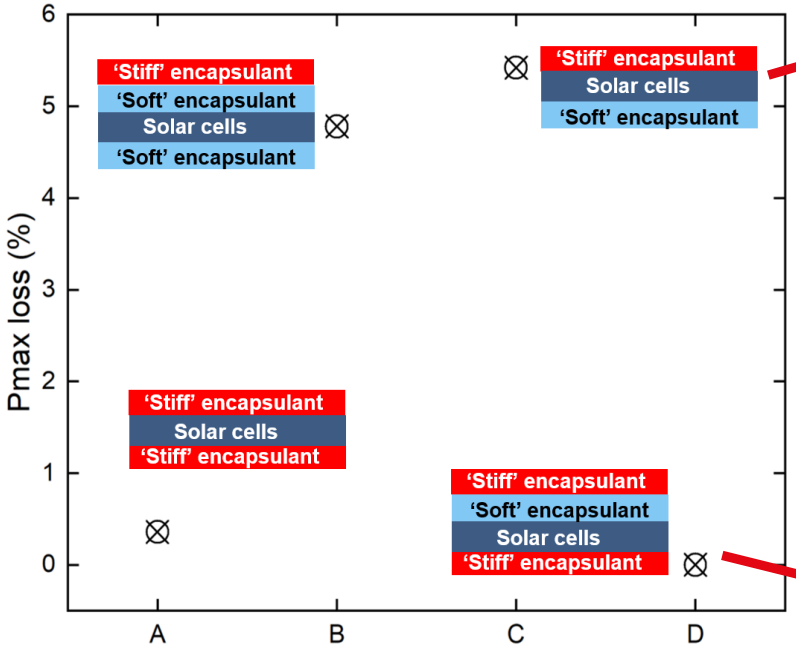
[2]

Test Conditions:

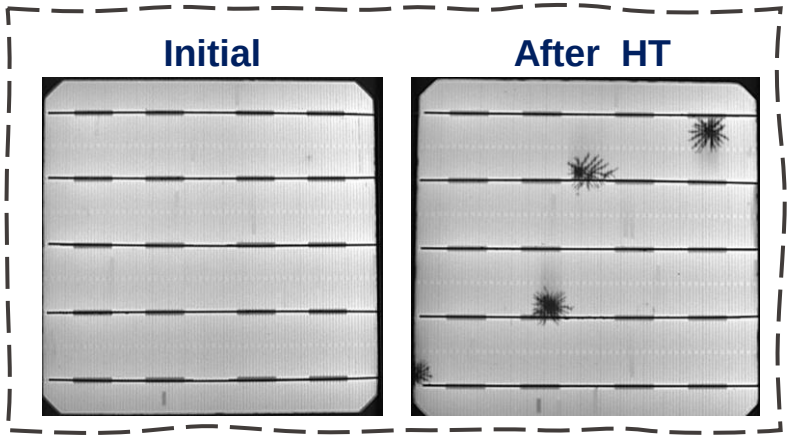
Velocity: 23.4 ± 1.5 m/s,
Distance: 1m from canon,
Diameter: 25 mm
Ice balls: 8.2 ± 0.4 g

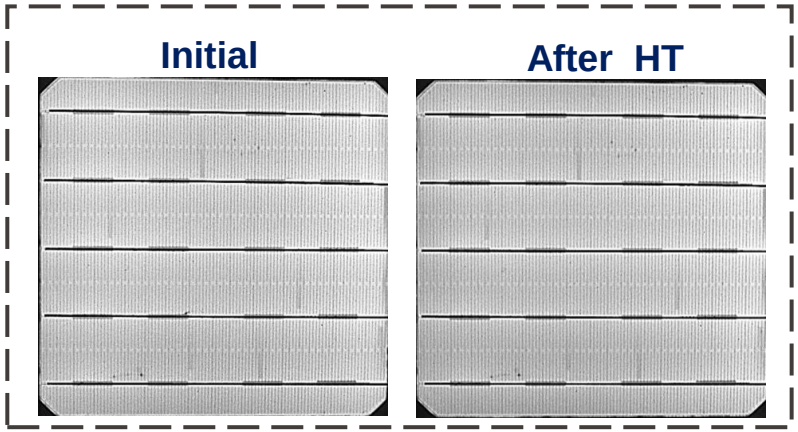
Source: [1]: A. Martins, PhD thesis, EPFL, [2] Lisco, F. et al., "Optimisation of the Frontsheet Encapsulant for Increased Resistance of Lightweight Glass-Free Solar PV Modules." Proc. of the 37 EUPVSEC (2020).

Challenges: Resistance to hail stones



"Combi encapsulant"





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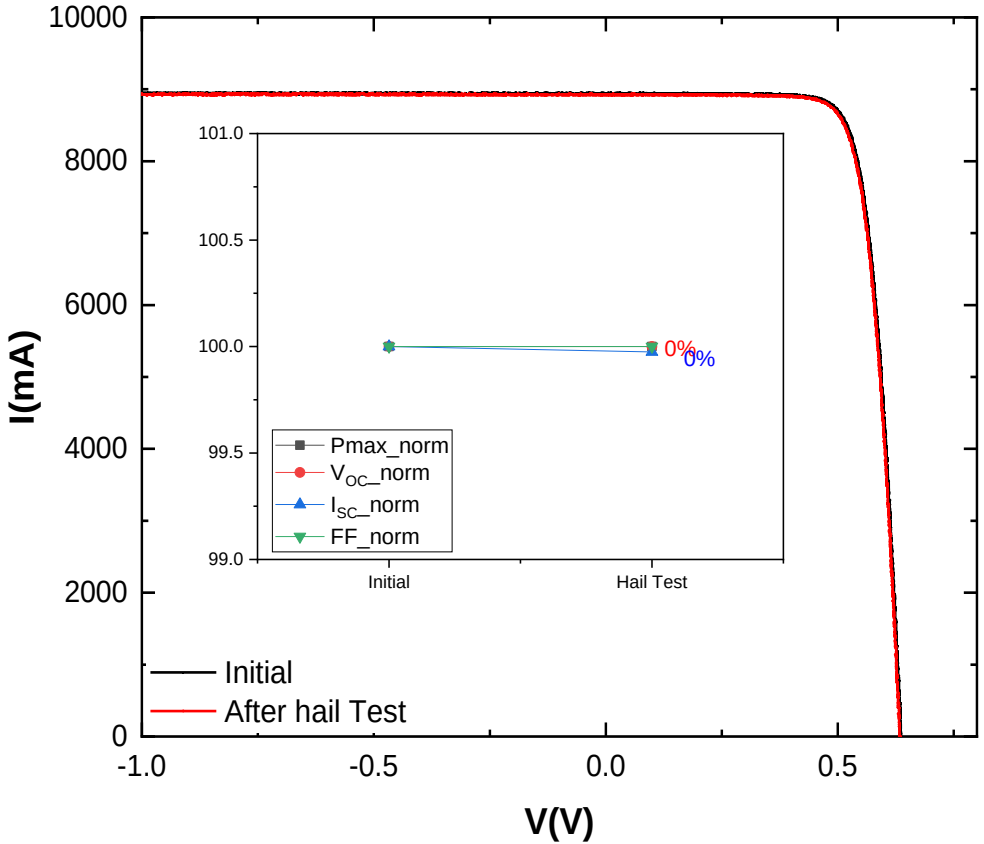
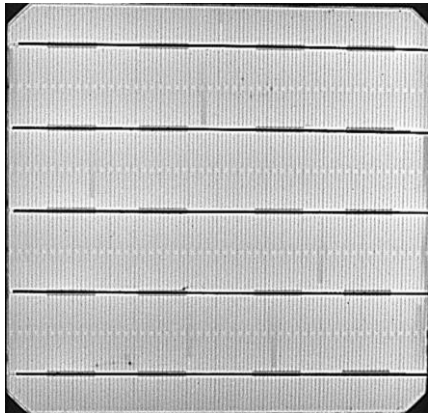
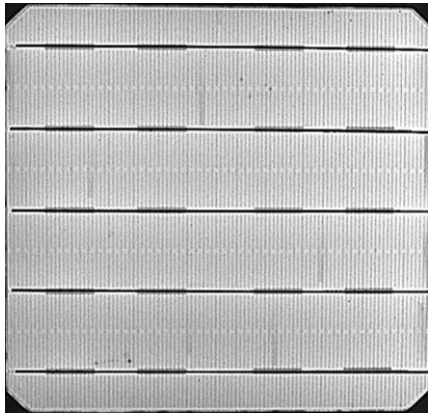
Challenges: Resistance to hail stones





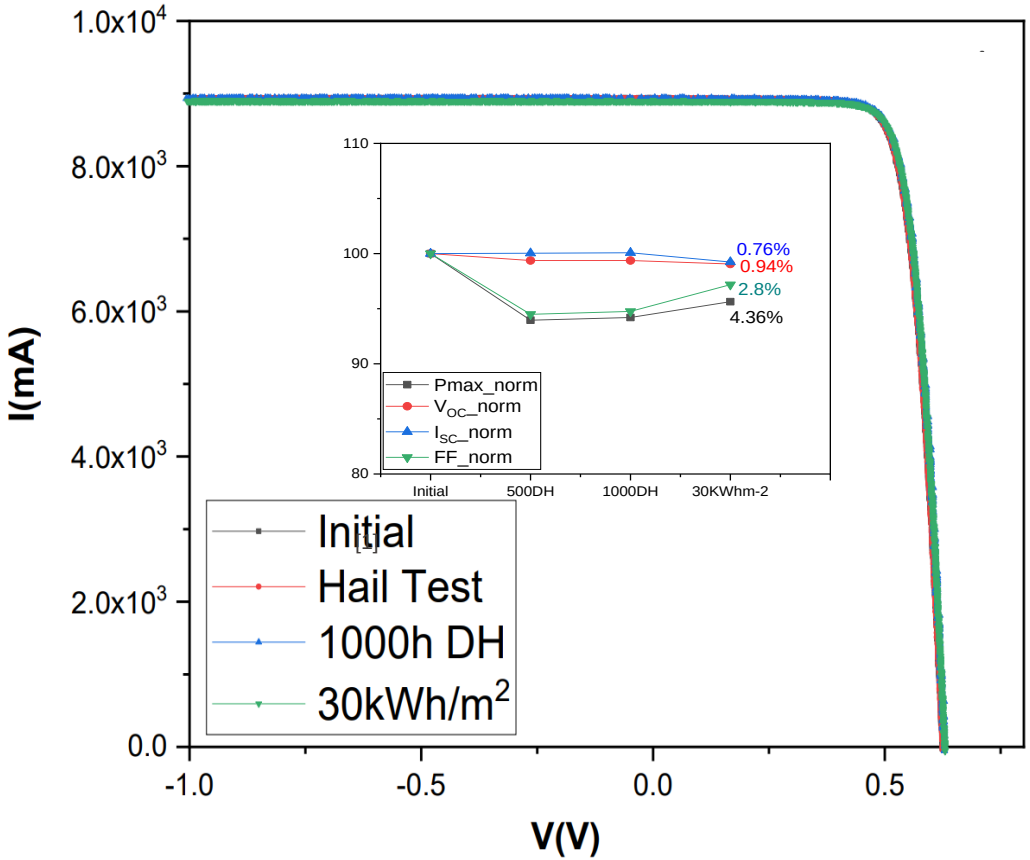
Initial

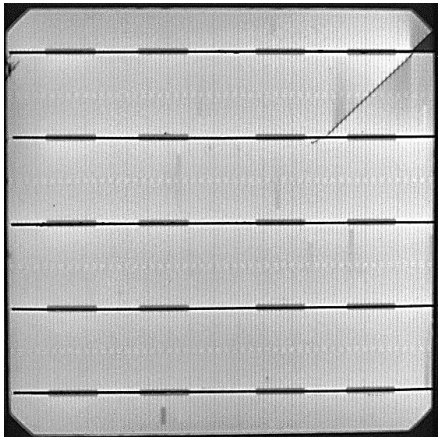


After hail test

Source: Lisco, F. et al., "Optimisation of the Frontsheet Encapsulant for Increased Resistance of Lightweight Glass-Free Solar PV Modules." Proc. of the 37 EUPVSEC (2020).

Challenges: Environmental stability





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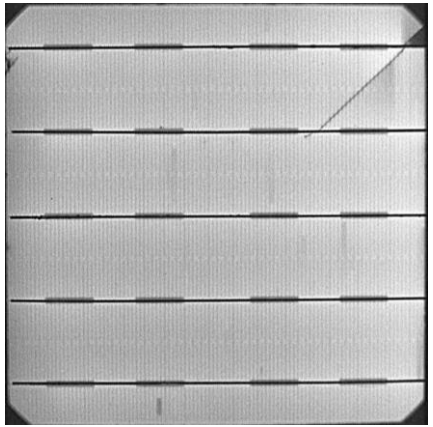
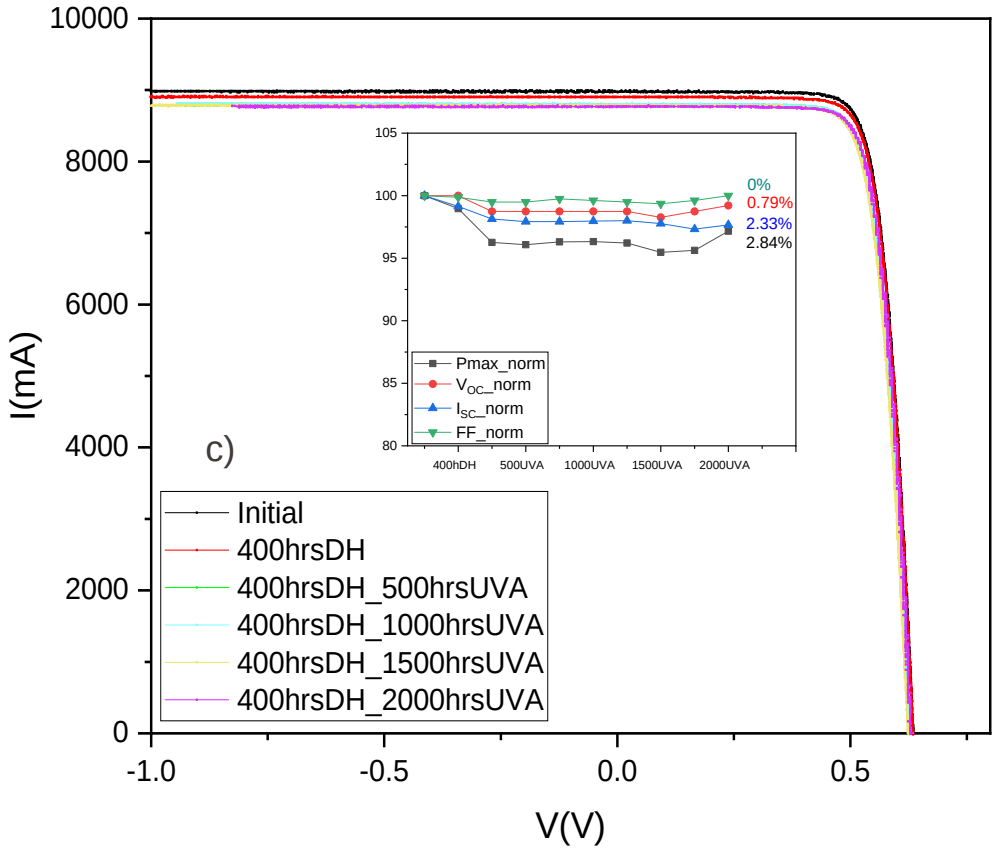
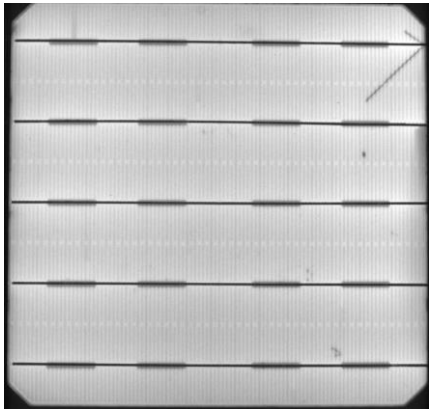


HT +1000hrs DH + 30kWh/m^2

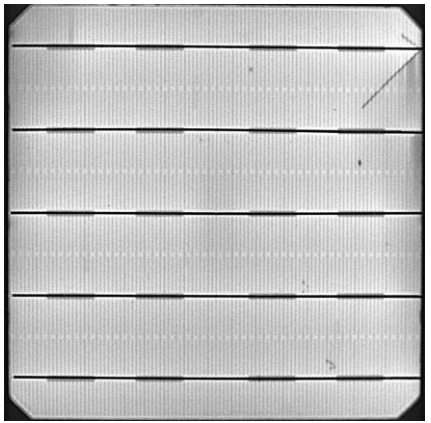
Source: Lisco, F. et al., "A" combi-encapsulant" for enhanced performance of glass-free lightweight crystalline silicon solar PV modules." 2021 IEEE 48th Photovoltaic Specialists Conference (PVSC). IEEE, 2021.

Challenges: Environmental stability





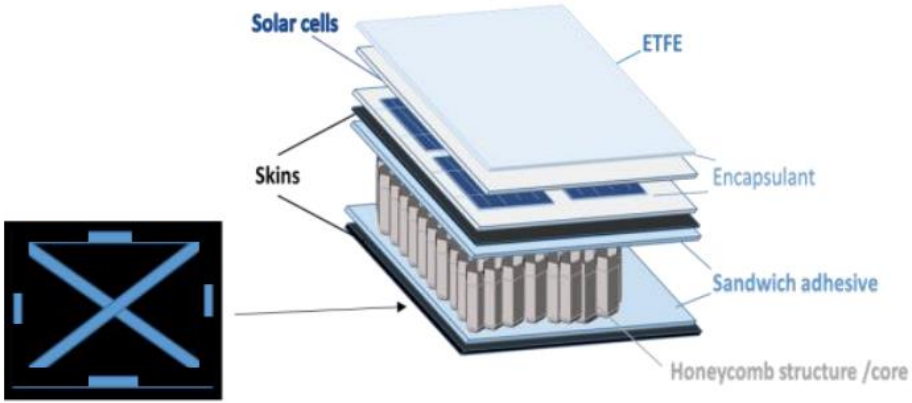
Initial

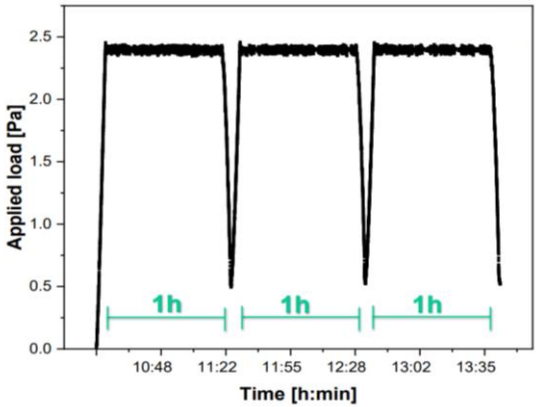


400 h DH +2000hrsUVA

Source: Lisco, F. et al., "A" combi-encapsulant" for enhanced performance of glass-free lightweight crystalline silicon solar PV modules." 2021 IEEE 48th Photovoltaic Specialists Conference (PVSC). IEEE, 2021.

Challenges: Building integration

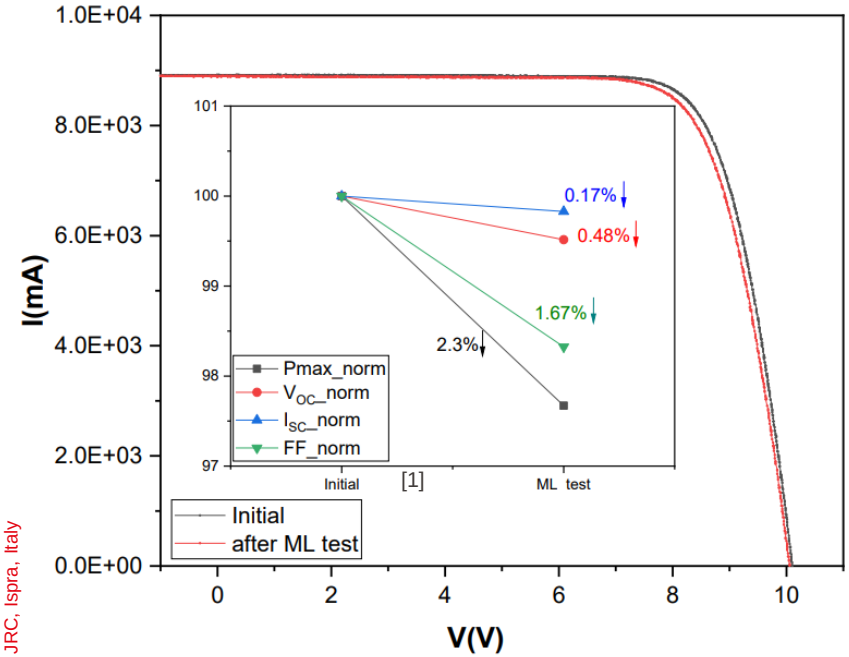


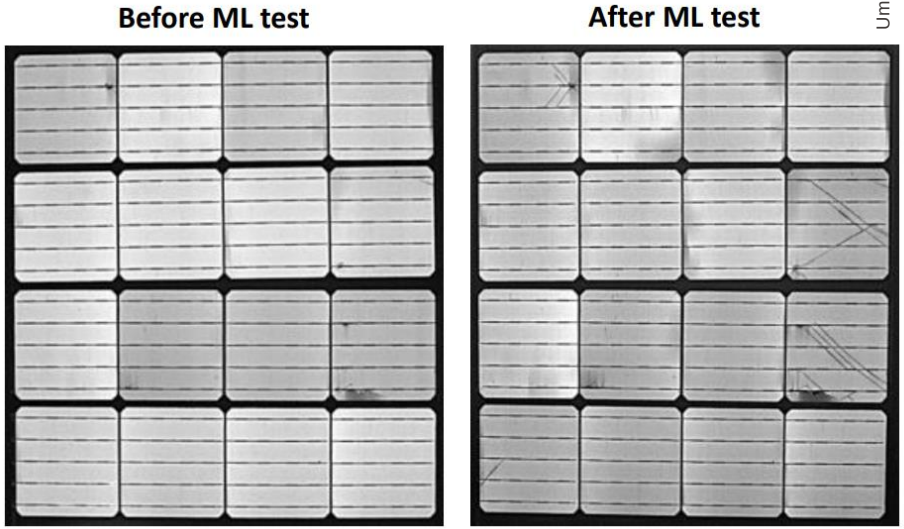


- This configuration survived the mechanical load test without debonding. None of the modules showed any visual damages after the hail test (no cracks visible by naked eye).

Source: Lisco, F. et al., "Glass-Free Lightweight Solar Modules for Integrated Photovoltaics: The Use of Velcro as an Alternative Mounting System." Proc. of 37th EUPVSEC, Lisbon, Portugal. 2020.

Challenges: Building integration

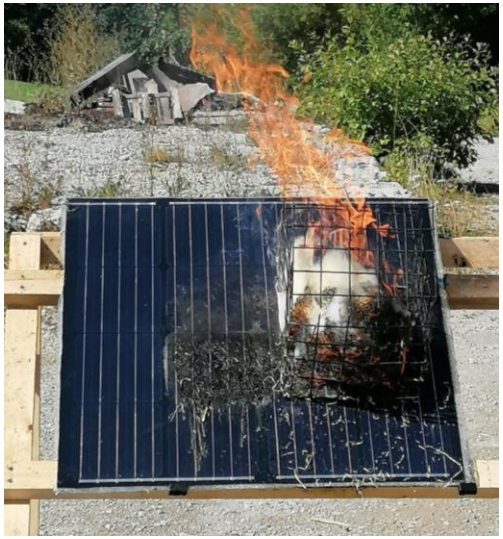




- The EL images acquired after the ML test show a few damages, initiated by defects already present in the solar cells. These defects possibly occurred after the lamination process and visible in the EL images taken prior to the test.

Source: Lisco, F. et al., "Glass-Free Lightweight Solar Modules for Integrated Photovoltaics: The Use of Velcro as an Alternative Mounting System." Proc. of 37th EUPVSEC, Lisbon, Portugal. 2020.

Challenges: Fire resistance



Sophia workshop, JRC, Ispra, Italy

Réaction	Contribution au feu
RF1	Pas de contribution
RF2	Faible contribution
RF3	Contribution acceptable
RF4	Contribution inacceptable

? to be verified..

Combustibilité

3	facilement combustible
4	moyennement combustible
5	difficilement combustible
5 (200°)	difficilement combustible à 200°
6q	quasi incombustible
6	incombustible

Degré de densité de fumée

1 :	Forte formation de fumée	> 90%
2 :	Formation de fumée moyenne	> 50-90%
3 :	Faible formation de fumée	< 50%

Source: F. Lisco et al., 20th Swiss National Photovoltaic Conference, Switzerland, 2022.

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Source: F. Lisco et al., 20th Swiss National Photovoltaic Conference, Switzerland, 2022.

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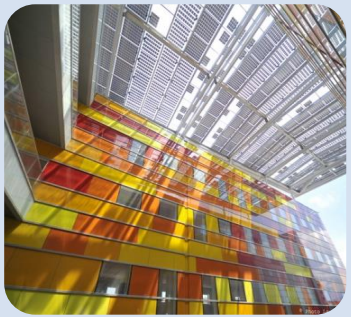
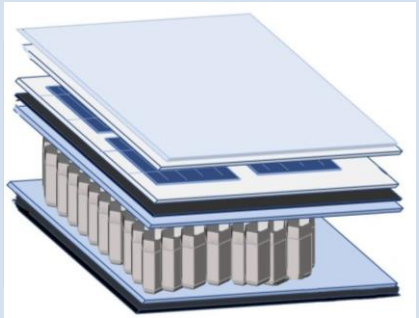
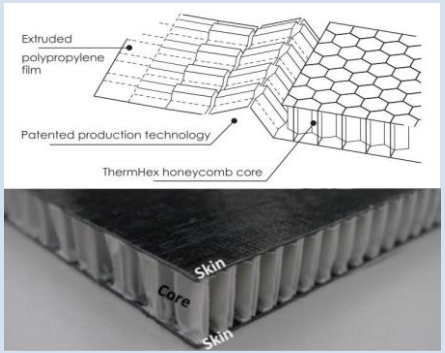
Going forward…



[1]



[2]



[3]

Generation -1

i. Glass/glass modules

ii. Very high weight

iii. High transportation cost

iV. Requires special attention to mounting of modules

Generation -2

i. Composite sandwich structure to replace glass.

ii. Aluminium core

iii. Reduction of mounting structure: target a cost reduction by 50%.

iV. Reduction of weight by 50 to 75% down to 6 kg/m^2

v. Integration of colour

Generation -3

i. Use of polymeric core instead of aluminium

ii. Use of recycled PET as a front sheet

iii. Environment friendly, lightweight and economic design

iV Weight reduction below 6 kg/m^2 possible

Source: [1]: https://www.climatechangenews.com/2013/10/25/new-transparent-solar-panels-could-turn-cities-into-power-stations/, [2]: F. Lisco et al., 20th Swiss National Photovoltaic Conference, Switzerland, 2022, [3] https://econcore.com/en/technology/thermhex-technology

LEADING EXPERTS WITH A COMMON GOAL …

EPFL

Imec

3S Swiss Solar Solutions

PCCL Polymer Competence Center Leoben

Delight consortium

SOLAXESS WHITE & COLOR SOLAR TECHNOLOGY

ofi FORTSCHRITT IN GUTEN HÄNDEN

Rembrandtin

econcore economic core technologies

kalyon PV

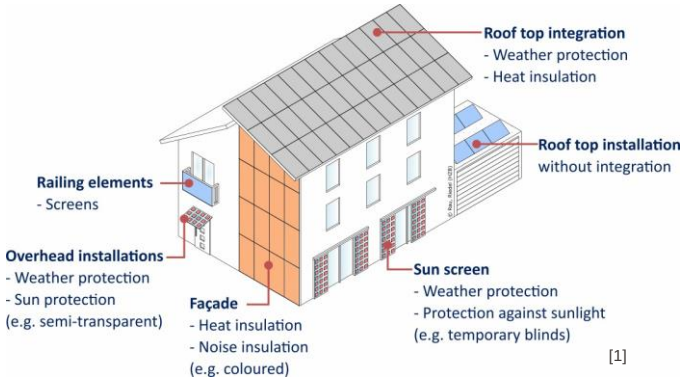


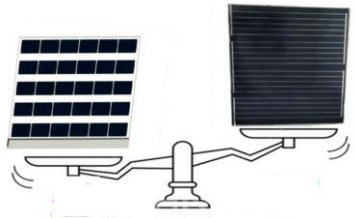
Fig: Illustration of different building integrated PV topologies

Source: [1] https://www.helmholtz-berlin.de/projects/baip/bipv_en.html

Delight Swiss Project : https://www.aramis.admin.ch/Texte/?ProjectID=51461

Ambitious goals…

- Weight reduction:
  - ≤ 6 kg/m² (glass free design)



- Aesthetic design:
  - coloured components and coatings

[1]

- Use of recycled PET as a frontsheet

- Use of materials sourced from Europe

Source: [1] https://www.3s-solar.swiss/bildergalerie

Delight

Targeted impact of the project

- *Impact on European solar power industry:*
  - This project will open up an untapped 4GW per year market for deploying lightweight BIPV as a commercial rooftop product.
  - Reduced dependance on import of products such as glass and aluminum frames from Asia.

- *Impact on reduction of LCOE:*
  - This project aims to develop a PV product using polymeric materials, which reduces the weight as well as the overall cost. Furthermore, the potential product will be integrated as a roof top rather than a roof with separate solar panels mounted on it/in it.

- *Life-cycle environnemental impact:*
  - The current glass/aluminum-based solar modules are not fully recyclable. Under this project, more circular and aesthetically pleasing module designs will be applied. Thus, it will allow each person to decrease their carbon footprint.

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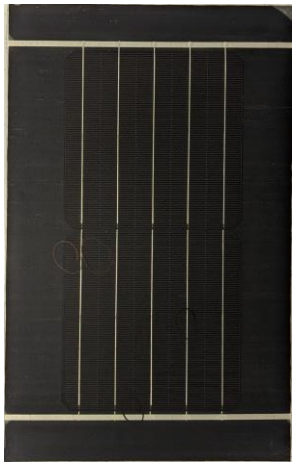
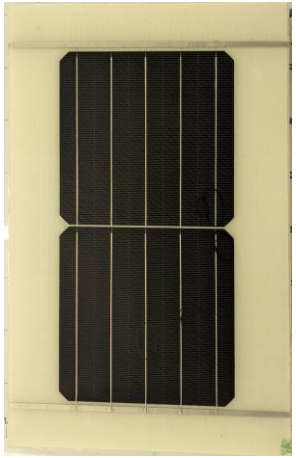
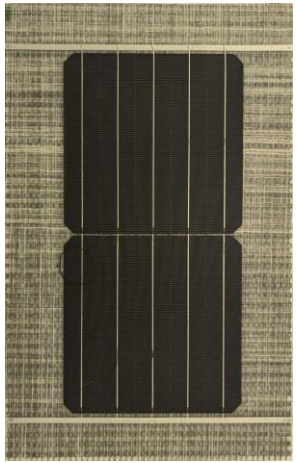
Initial exhibits being developed under Delight project

Frontsheet
Solar cells
Encapsulant
Skin
Core







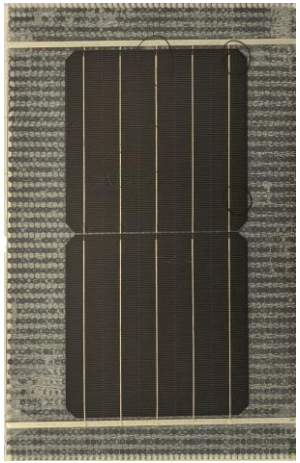


Exhibit	1	2	3	4
Colour	Black	White	black core + greyish skins	black core + transparent skins
Thickness	12 mm	12 mm	11 mm	10 mm
Core	White PP core	White PP core	Black PET core	Black PET core
skin	Black PP/GF	White PP/GF	Greyish PET/GF	Transparent PET
Weight	451 g	483 g	421 g	334 g

Source:Jonathan G. et al., LIGHT AS HEAVEN, STRONG AS HELL: TESTING HONEYCOMB-BASED LAMINATES FOR LIGHT-WEIGHT C-SI PV APPLICATIONS, EUPVSEC (manuscript under preparation), 2023.

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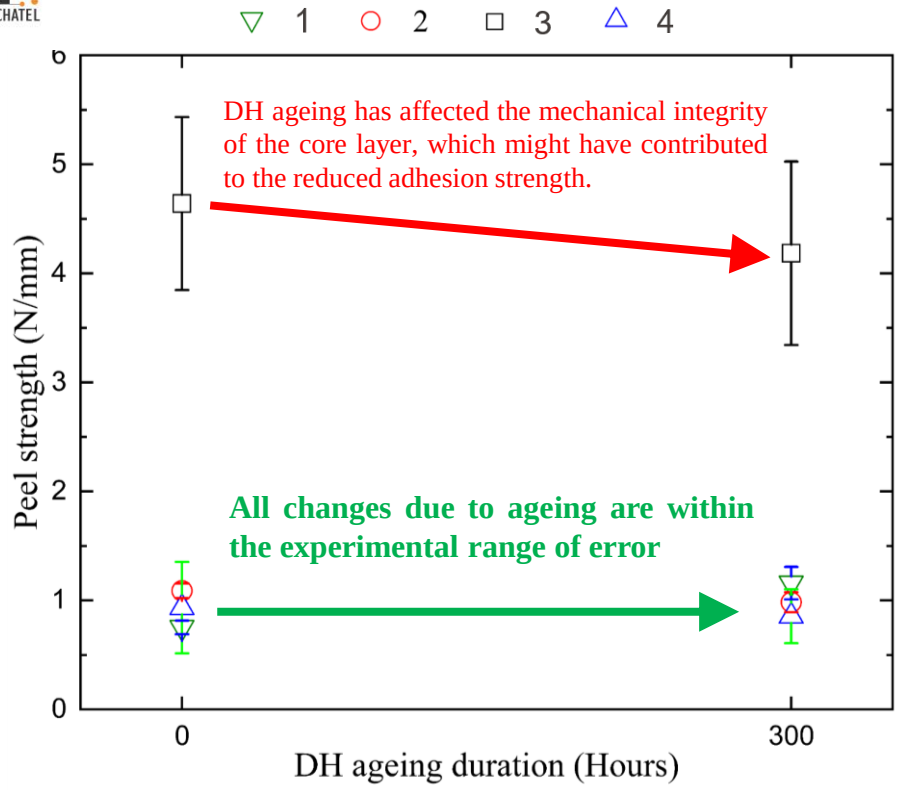
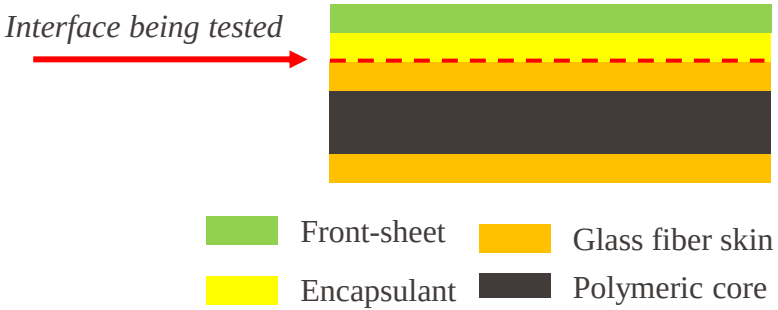
Peel test



- ‘1’: White PP core/Black PP/GF
- ‘2’: White PP core/White PP/GF
- ‘3’: Black PET core/Greyish PET/GF
- ‘4’: Black PET core/Transparent PET



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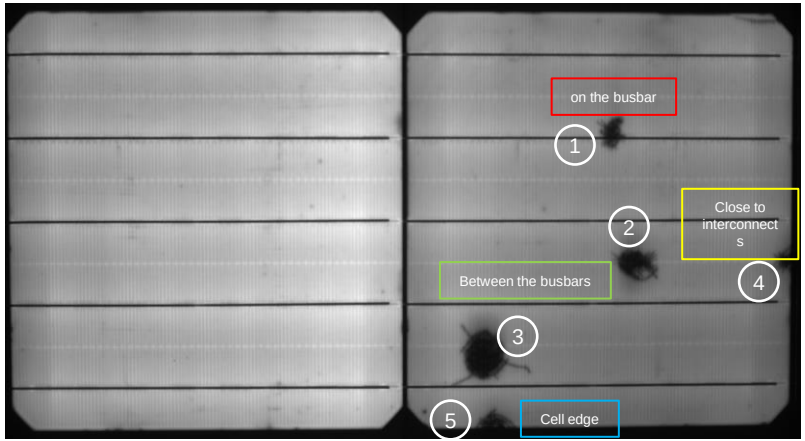
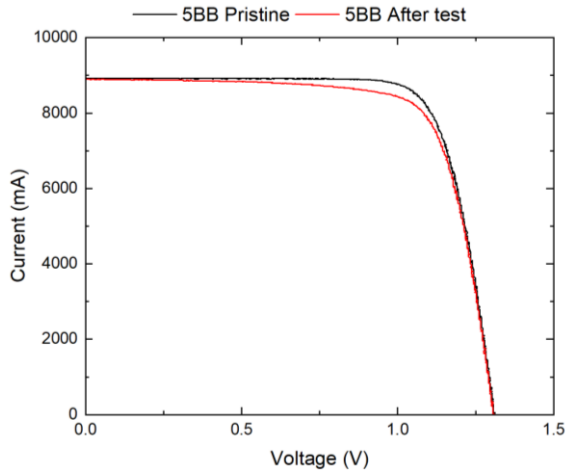
Hail test: 5BB- White PP core/Black PP/GF

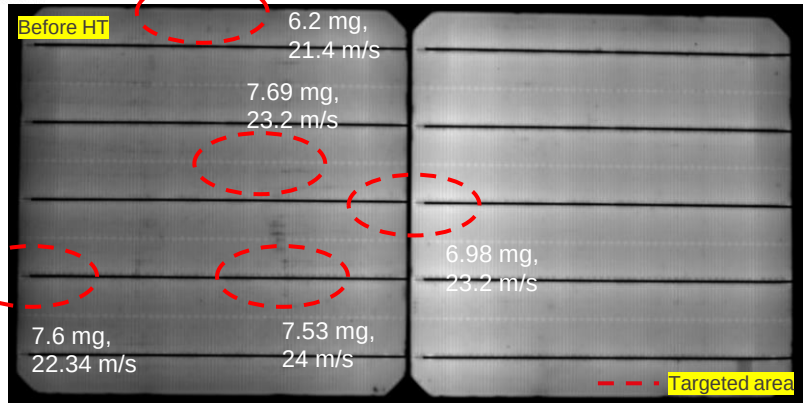


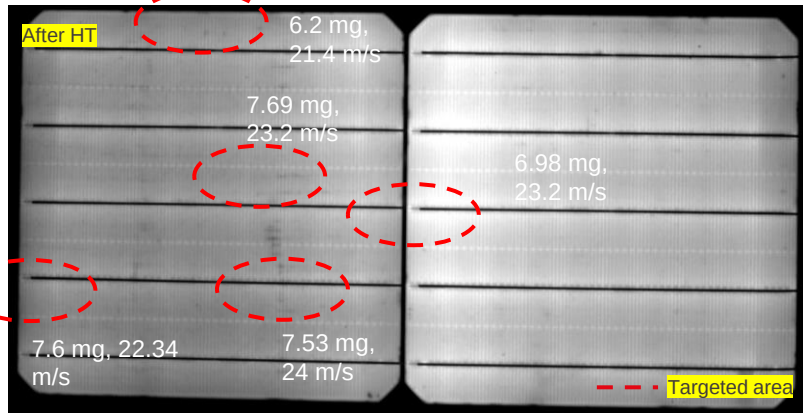
Spot #	Spot	Mass of the ice ball (mg)	Speed of the ice ball (m/s)
1	On the busbar	6.89	22.24
2	Between the busbars	6.77	21.09
3	Between the busbars	7.21	24.89
4	Close to interconnects	7.64	21.89
5	Cell edge	6.94	22.58
6	Edge of a module	7.21	23.1
7	Corner of a module	6.74	22.8

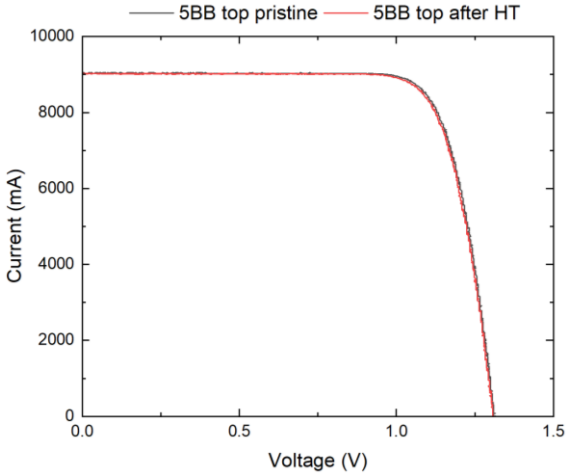


	I_{sc} (mA)	V_{oc} (V)	FF (%)	P_{max} (W)	% change in P_{max}
Pristine	8918.42	1.31	77.4	9.042	
After HT	8901.69	1.31	74.7	8.692	-3.87

Hail test: 5BB-Ref (glass/glass)







	I_{sc} (mA)	V_{oc} (V)	FF (%)	P_{max} (W)	% change in P_{max}
Pristine	9024.09	1.309	78.4	9.265	
After HT	9042.28	1.309	78.3	9.261	-0.04

Hail test: 10BB- White PP core/Black PP/GF

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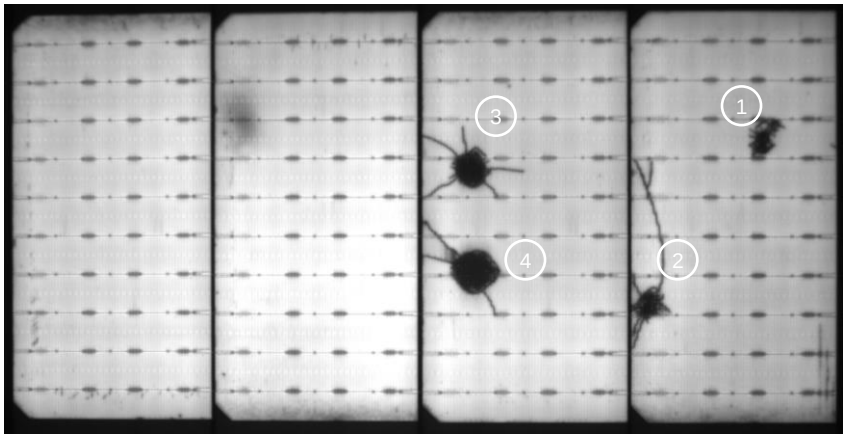
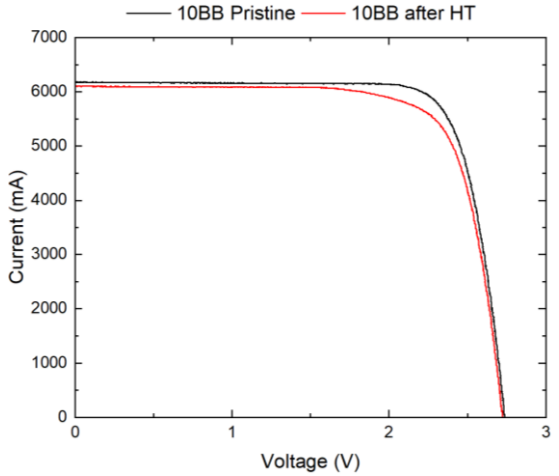
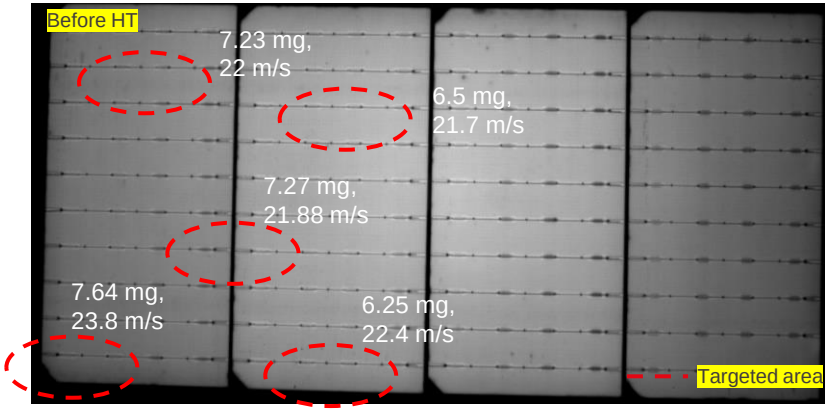


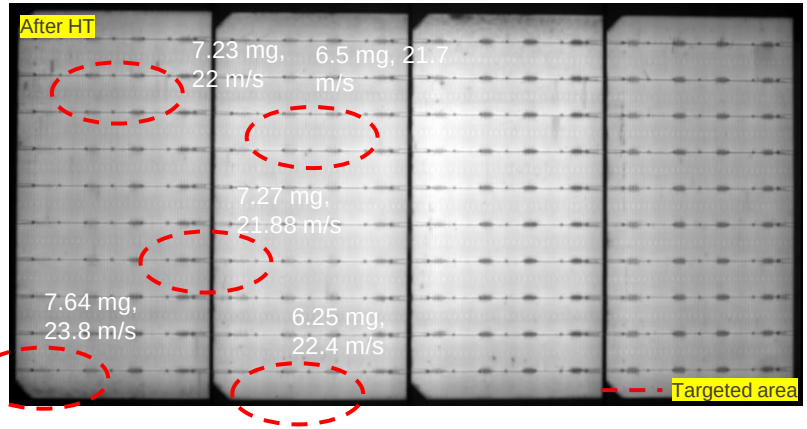
Spot #	Spot	Mass of the ice ball (mg)	Speed of the ice ball (m/s)
1	Between the busbars	7.36	21.7
2	Close to interconnects	7.34	22.82
3	On the busbar	6.9	22.47
4	On the busbar	7.2	22.84
5	Edge of a module	7.28	21.25
6	Corner of a module	6.89	23.24

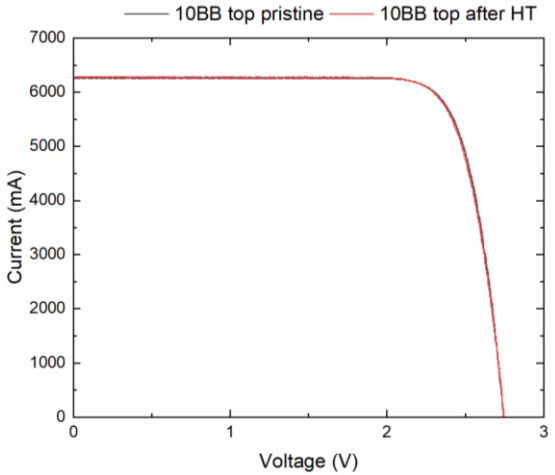


	I_{sc} (mA)	V_{oc} (V)	FF (%)	P_{max} (W)	% change in P_{max}
Pristine	6177.25	2.738	79.3	13.409	
After HT	6104.93	2.724	76	12.6	-6.03

Hail test: 10BB-Ref (glass/glass)

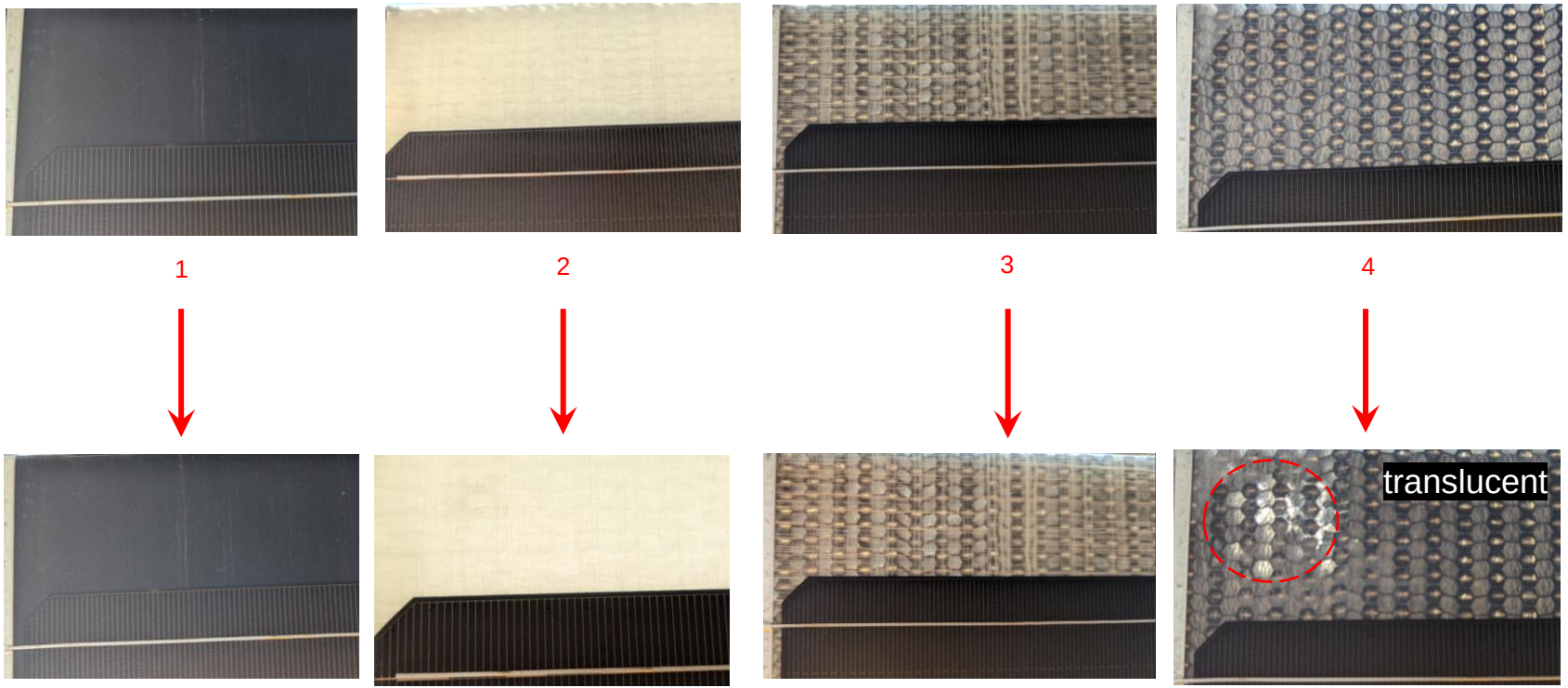






	I_{sc} (mA)	V_{oc} (V)	FF (%)	P_{max} (W)	% change in P_{max}
Pristine	6263.11	2.747	80.6	13.858	
After HT	6268.56	2.747	80.1	13.809	-0.35

Visual damage on modules after hail test



- ‘1’: White PP core/Black PP/GF
- ‘2’: White PP core/White PP/GF
- ‘3’: Black PET core/Greyish PET/GF
- ‘4’: Black PET core/Transparent PET

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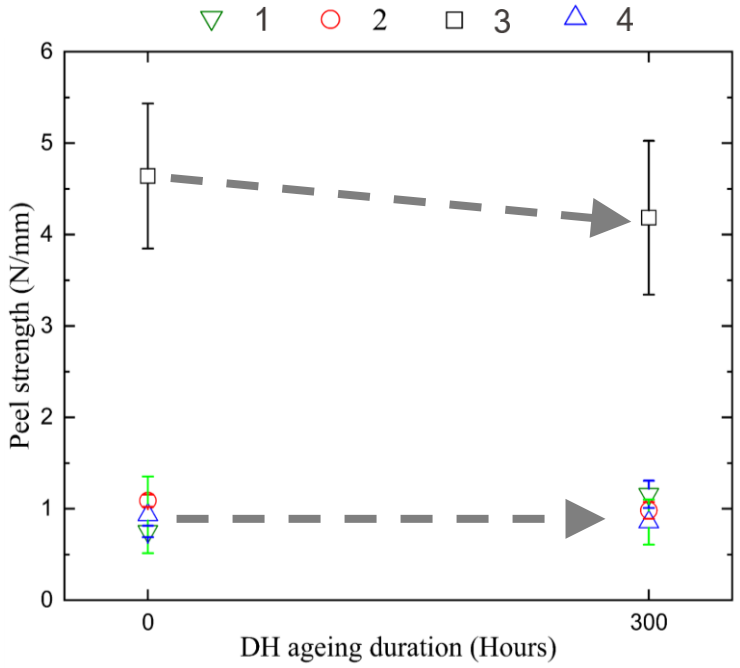
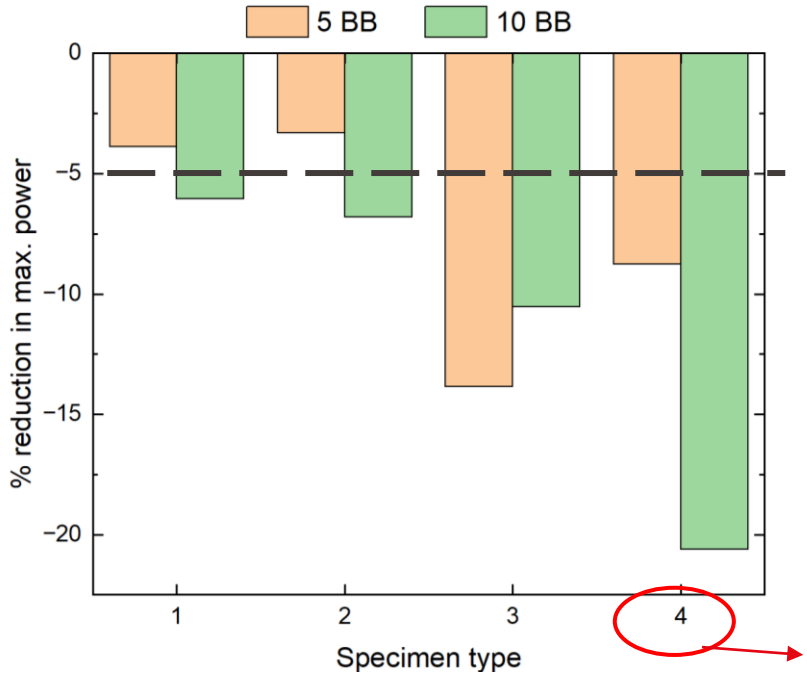
Summary

Peel test



- ‘1’: White PP core/Black PP/GF
- ‘2’: White PP core/White PP/GF
- ‘3’: Black PET core/Greyish PET/GF
- ‘4’: Black PET core/Transparent PET

Hail test



- The core layer for specimen ‘4’ suffered damage because of hails.

*: https://www.aleo-solar.com/hail-storms-can-be-dangerous-for-solar-systems/

Conclusions

- LW modules based on aluminium honeycomb structure is robust and has been shown to perform well against:
  - Hail test
  - Environmental stressors
  - Static Mechanical Load
  - Fire test

However, it is not yet a certified product and further research is needed to make the structure cost effective.

- The lessons learned through optimizing the aluminium honeycomb based structure will be used to improve the performance of the polymeric honeycomb structure under the Delight project.

Acknowledgements

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