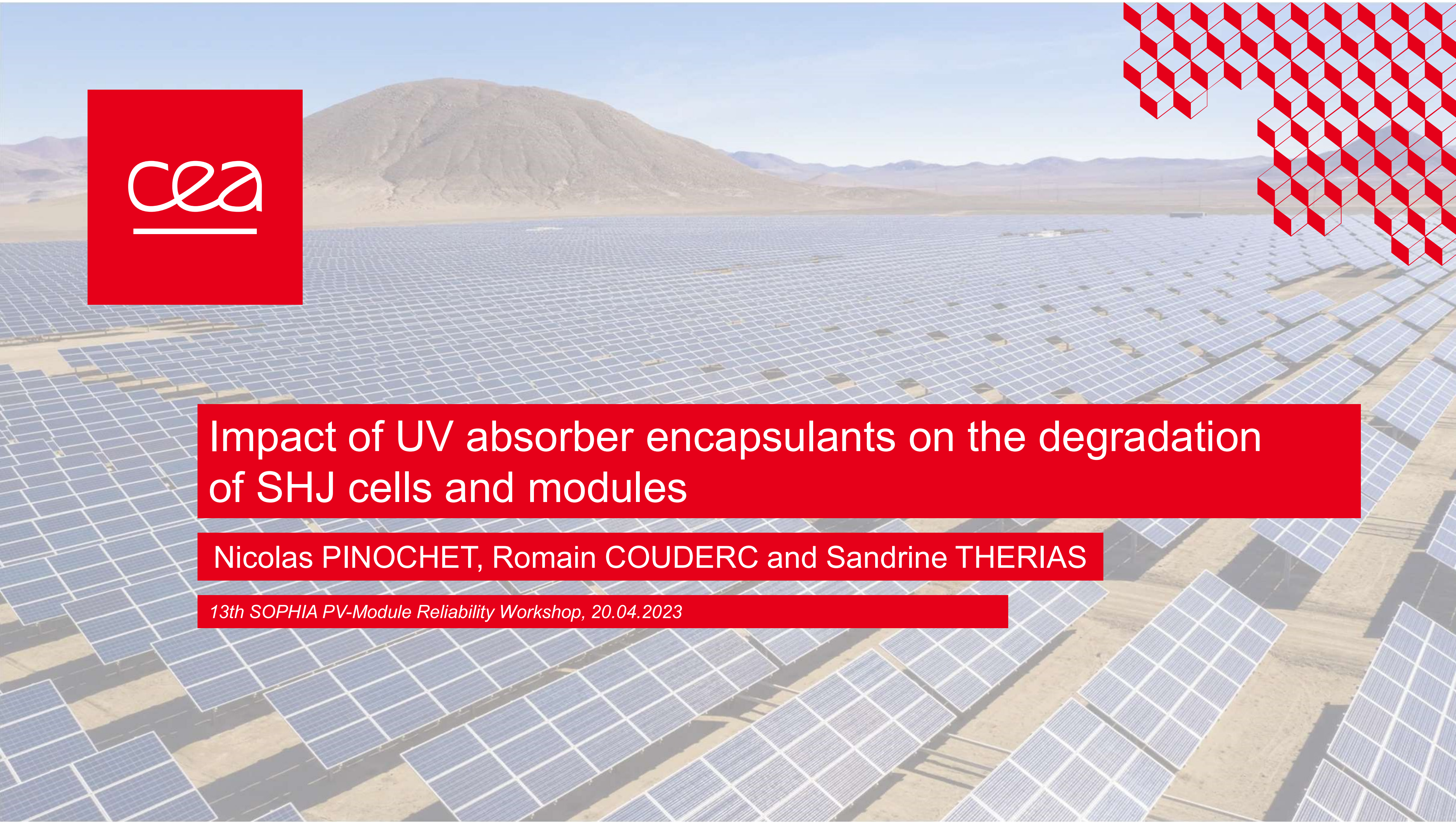
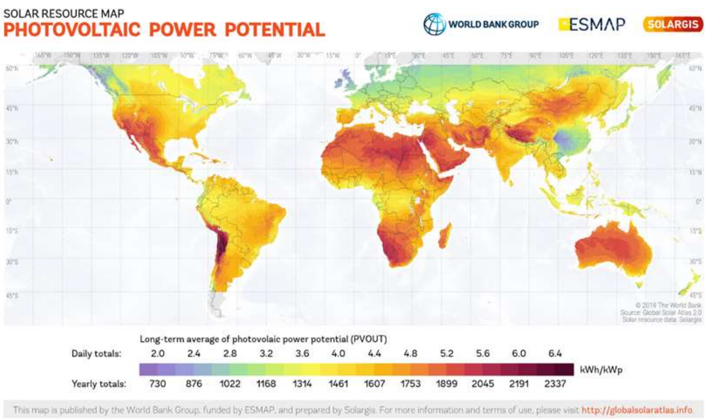


Impact of UV absorber encapsulants on the degradation of SHJ cells and modules

Nicolas PINOCHET, Romain COUDERC and Sandrine THERIAS

13th SOPHIA PV-Module Reliability Workshop, 20.04.2023

Context

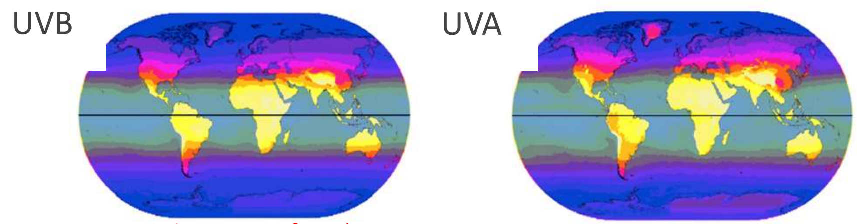


Solar resource map from Solar GIS

EDF PV plant in Atacama desert

UV light is detrimental to most PV modules

- Cell UVID
- Encapsulant degradation
- Delamination
- Backsheet yellowing and cracking
- …



0,3 à 40 mW.m^{-2}.nm^{-1} @ 305 nm

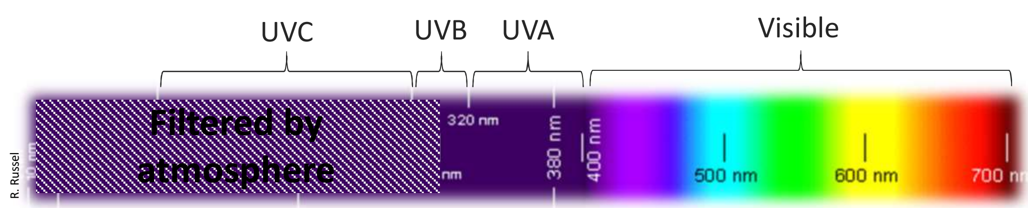
20 à 260 mW.m^{-2}.nm^{-1} @ 380 nm

Annual mean of UV irradiance [1]

High irradiance environments

High UV irradiance

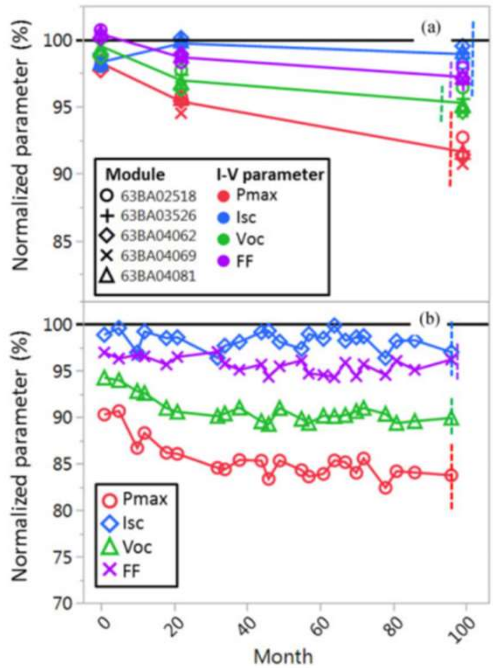
UV induced degradations



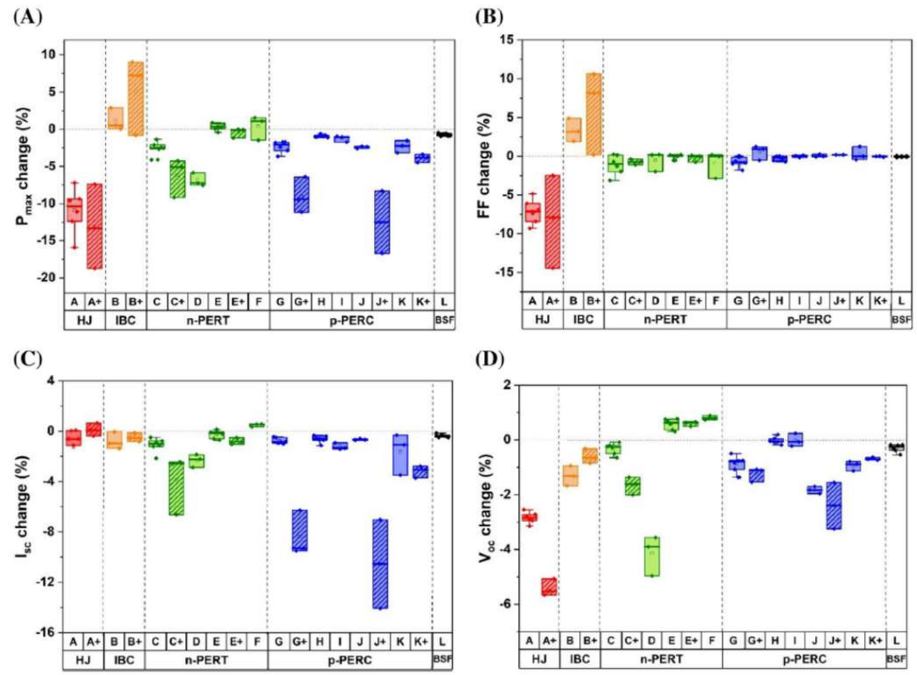
Spectral definition of UVA and UVB

[1] N.G. Jablonski *et al.*, Human skin pigmentation as an adaptation to UV radiation, PNAS, 2010.

UV ageing of Silicon HeteroJunction (SHJ)



(a) Indoor and (b) outdoor IV measurements for a system of 5 SHJ modules aged 10 years outdoor [2]



IV parameters of differents cells (SHJ, IBC, n-PERT and p-PERC) after 2000 h of UV [3]

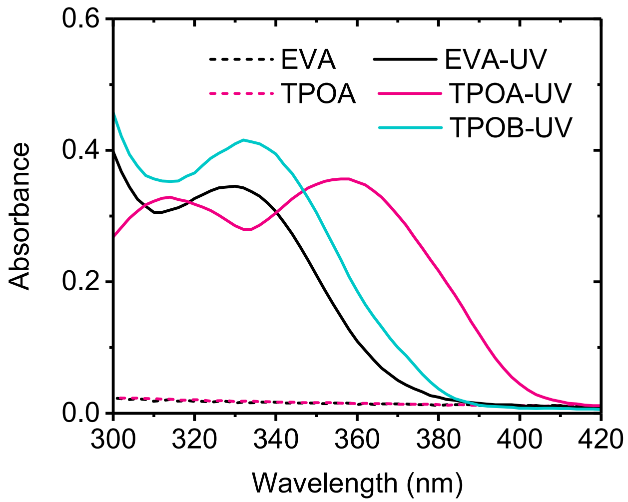
SHJ sensitive to UV

V_{oc} and FF losses

[2] Jordan et al., SHJ system field performance, IEEE JPV, 2018.
[3] Sinha et al., UV induced degradation of high-efficiency silicon PV modules with different cell architectures, PIP, 2022.

Outline

Mini-modules production

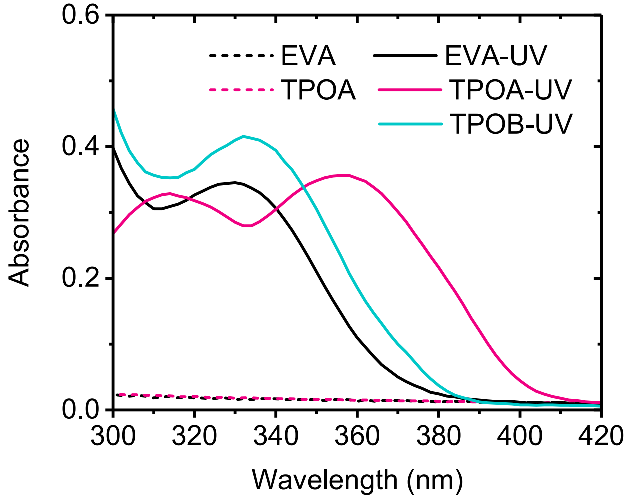


UV absorption spectra of the encapsulants

5 × 2 glass-glass mini-modules

Encapsulant	P_{max} (W)	I_{sc} (A)	V_{oc} (V)	FF (%)
EVA	5.10 ± 0.01	9.38 ± 0.01	0.736 ± 0.001	73.9 ± 0.2
TPOA	5.16 ± 0.01	9.43 ± 0.01	0.738 ± 0.001	74.2 ± 0.1
EVA-UV	5.04 ± 0.03	9.29 ± 0.05	0.736 ± 0.002	73.7 ± 0.2
TPOA-UV	5.07 ± 0.01	9.23 ± 0.01	0.737 ± 0.001	74.5 ± 0.3
TPOB-UV	5.12 ± 0.01	9.34 ± 0.01	0.737 ± 0.001	74.3 ± 0.1

Accelerated UV ageing



UV absorption spectra of the encapsulants

5 × 2 glass-glass mini-modules

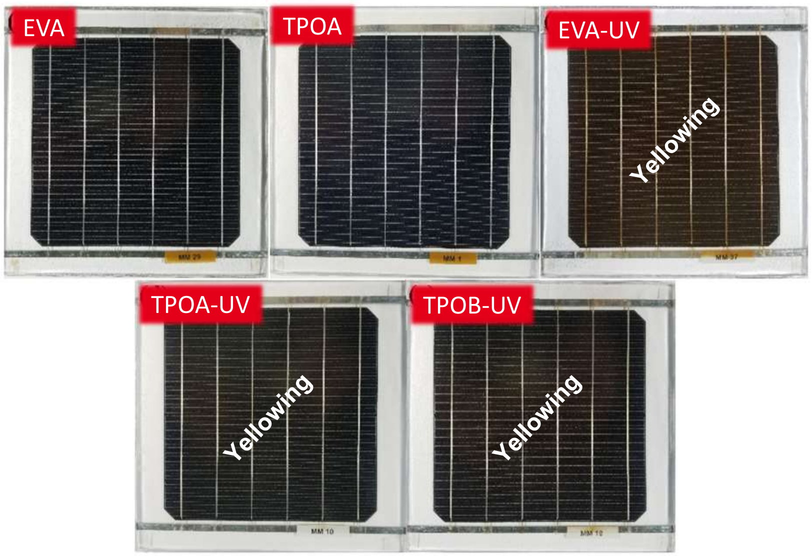
Atlas Ci5000 UV chamber

Filtered xenon

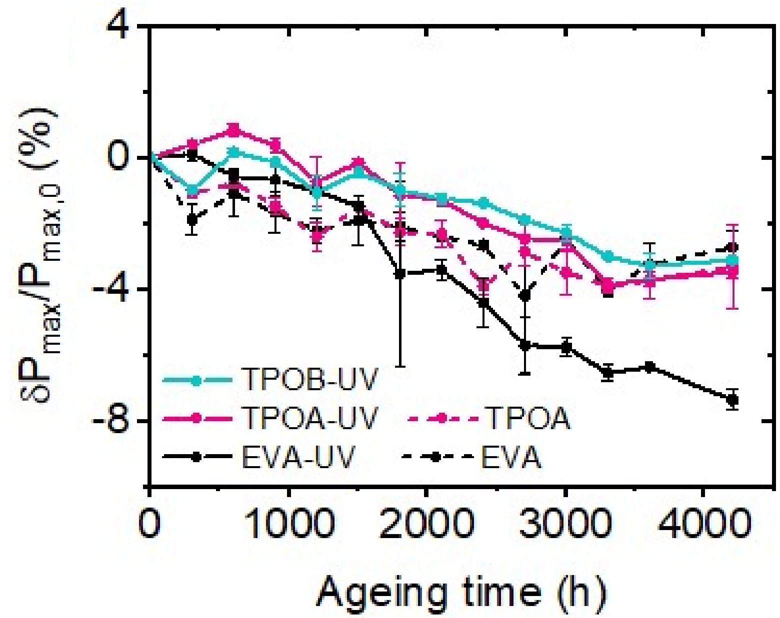
83 °C

100 W/m²
(300-400 nm)

Yellowing of the modules



Front side of the mini-modules after 4200 h



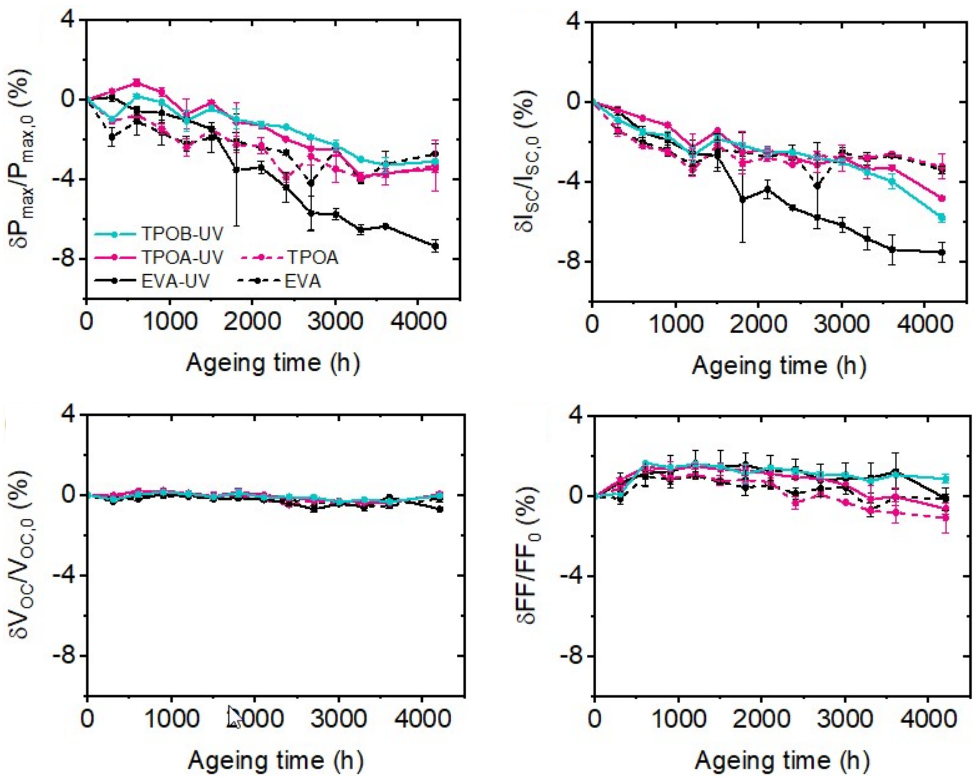
Mini-modules relative losses during UV accelerated ageing

Yellowing of the encapsulant with UV absorbers

Difficult early detection with visual inspection

P_{max} losses in between 3 and 8 % after 4200 h

Different losses of SHJ under UV



Mini-modules performances during UV accelerated ageing

Stable V_{oc}

No passivation degradation

Initial I_{sc} losses

Obscuring of glass and TCO

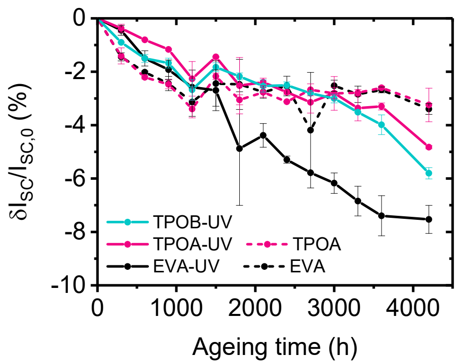
Additionnal I_{sc} losses for EVA-UV, TPOA-UV et TPOB-UV

Encapsulant transmission losses

FF gain then *FF* losses

Light soaking then R_{series} losses

Acceleration of the yellowing



Arizona desert (6h/day) [4]

Accelerated ageing test	Outdoor ageing	Encapsulant yellowing under UV
t: 4200 h	t: ?	e_a : 30 to 60 kJ/mol [5]
T: 83 °C	T: 55 °C	
I: 100 W/m²	I: 45 W/m²	

Acceleration factor calculation

- **Arrhenius law**: $k \propto e^{-\frac{e_a}{RT}}$
- **Law of reciprocity**: $k \propto It$

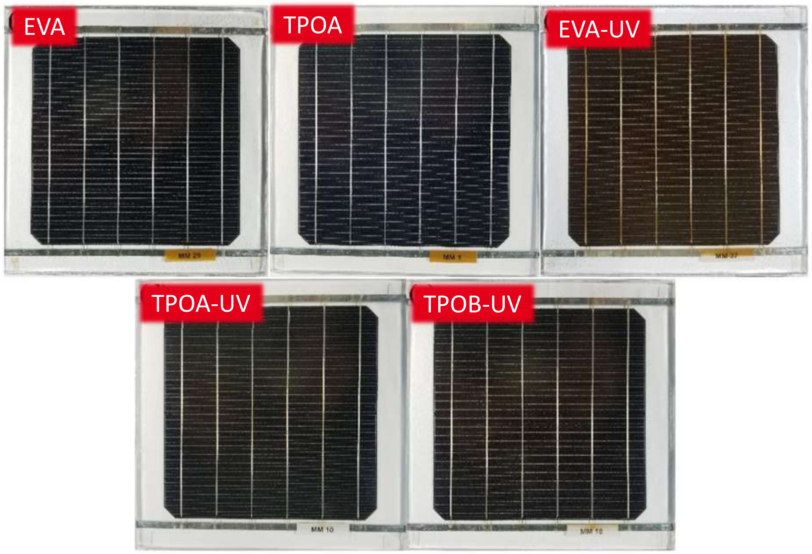
Outdoor ageing

t: 10 - 24 y

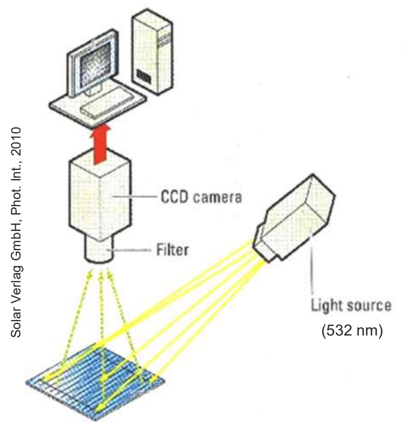
Strong yellowing may happen in high irradiance environments

[4] Liu et al., UV degradation behavior of polymeric backsheets for PV modules *Solar Energy*, 2014.
[5] Miller et al., Degradation in PV encapsulant transmittance: esults of the first PVQAT TG5 artificaial weathering study, PIP, 2018.

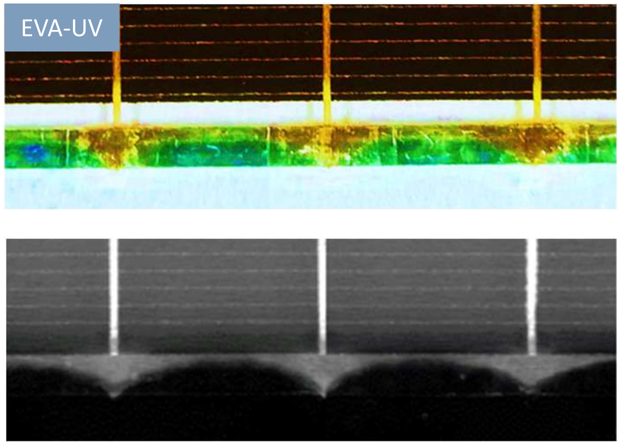
Early detection of yellowing



Front side of the mini-modules after 4200 h



PL imaging



Comparaison of yellowing patterns and PL

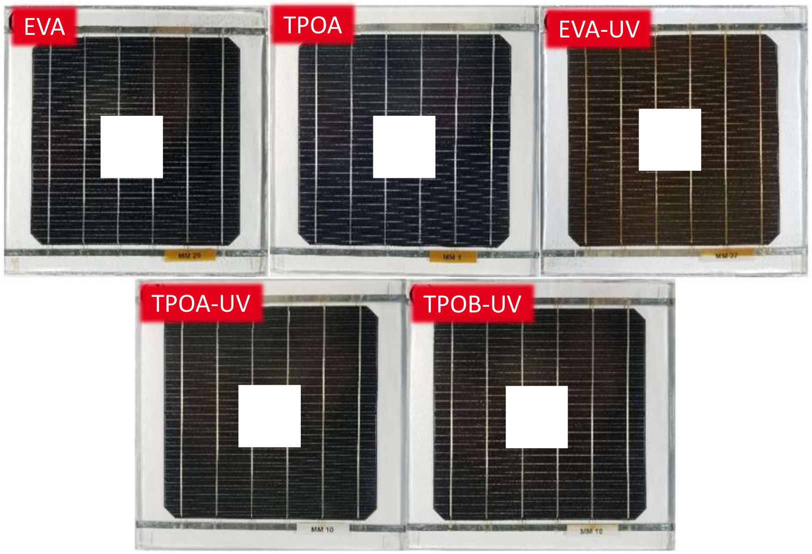
Yellowing of the encapsulant with UV absorbers

Difficult early detection with visual inspection

Chromophors involved in yellowing emit under 532 nm excitation

Early detection possible with 532 nm PL imaging

Early detection of yellowing

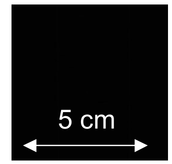
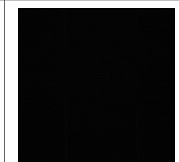
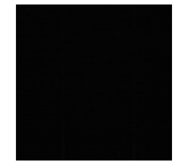
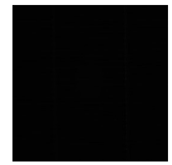
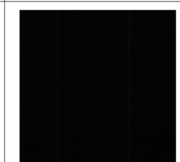
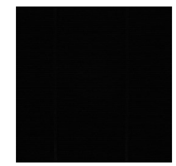
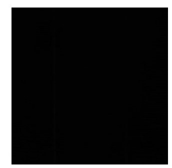
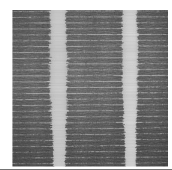
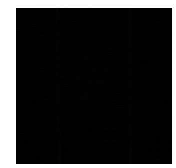
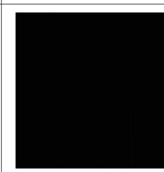
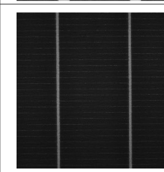
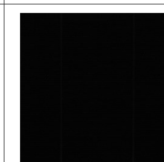
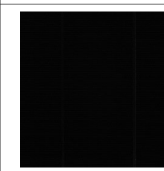
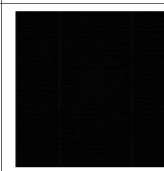
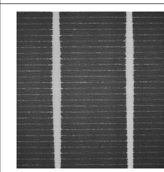
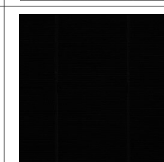
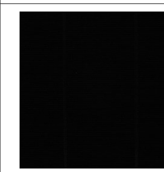


Front side of the mini-modules after 4200 h

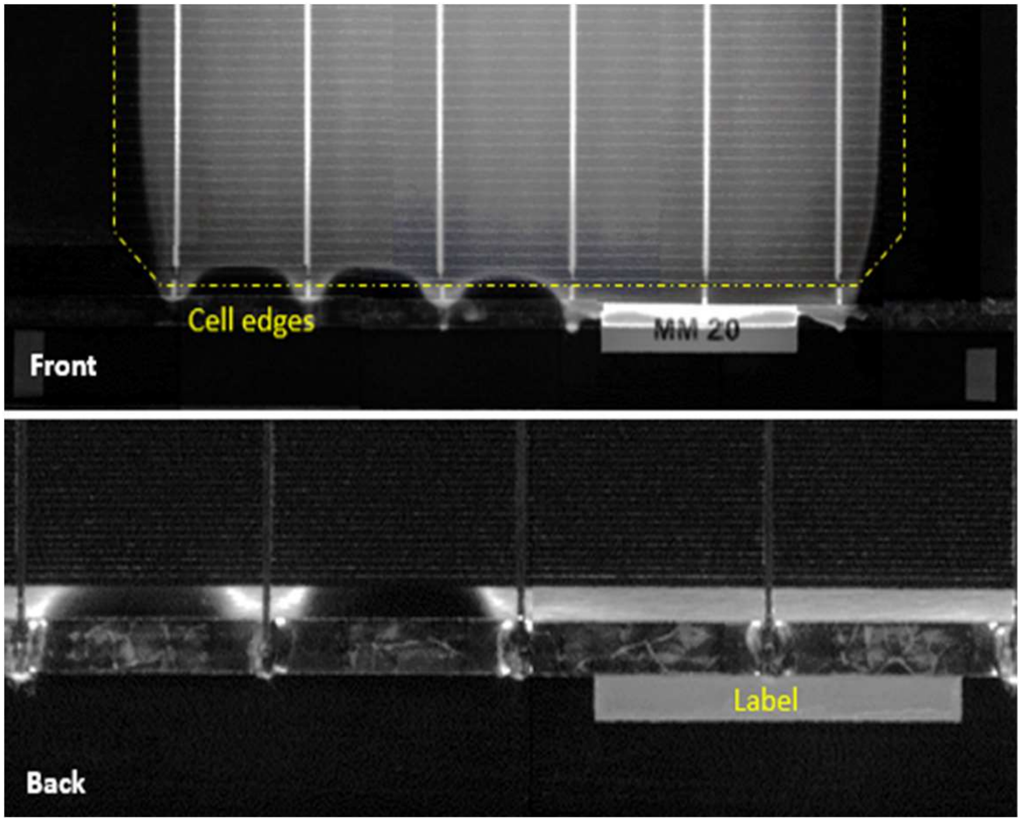
Chromophors involved in yellowing emit under 532 nm excitation

Early detection possible with 532 nm PL imaging

PL images in the center of the mini-modules

Encapsulant	Front, 0 h	Front, 4200 h	Back, 0 h	Back, 4200 h
EVA				
TPOA				
EVA-UV				
TPOA-UV				
TPOB-UV				

Chromophors in 3D



Front and rear PL images of an aged TPOB-UV mini-module

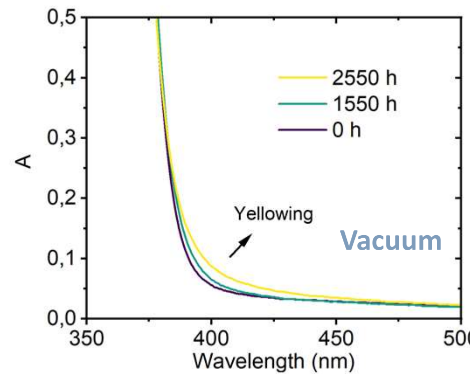
Photobleaching caused by oxygen diffusion

Yellowing limited to the front

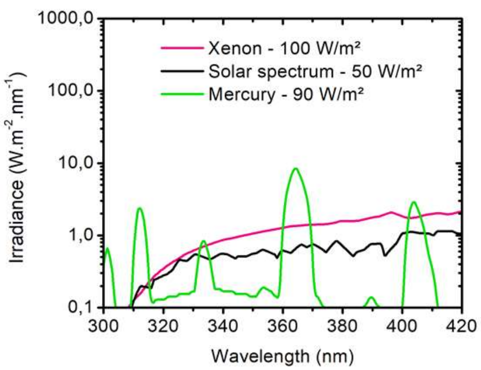
UV ageing of thin films samples

Samples sealed in glass capsules in UV chamber

λ	Mercury
T	65 °C
I	90 W/m² (300-400 nm)
t	2550 h



Absorbance of TPOB-UV after 0, 1550 and 2550 h of UV ageing

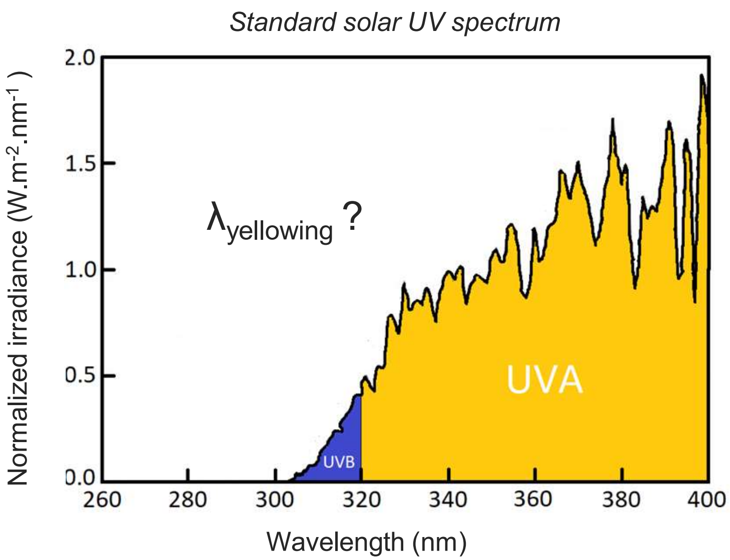


UV spectra

Yellowing only visible for glass sealed samples

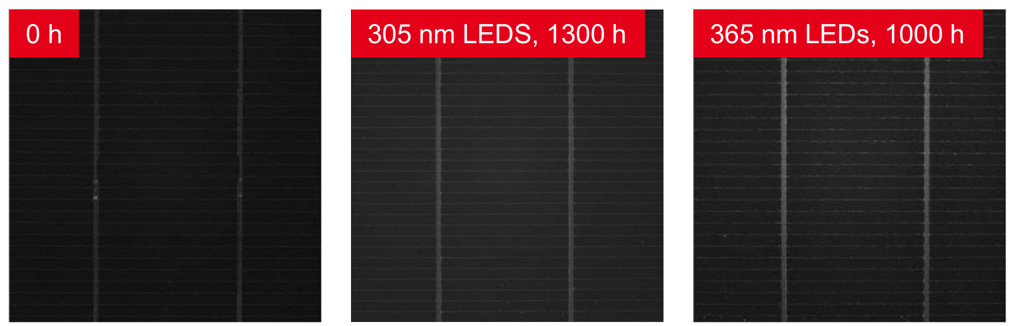
Chromophores created under UV and without oxygen: photolytic mechanism

Spectral impact on the yellowing



UVA and UVB generate chromophores

Visual inspection UV ageing under UV LEDs



PL images of modules TPOB-UV centre (increased integration time)

N. Pinochet, R. Couderc, S. Therias.
Solar cell UV-induced degradation or module discolouration: between the devil and the deep-yellow sea.
Progress in Photovoltaics: Research and Applications

Outdoor ageing

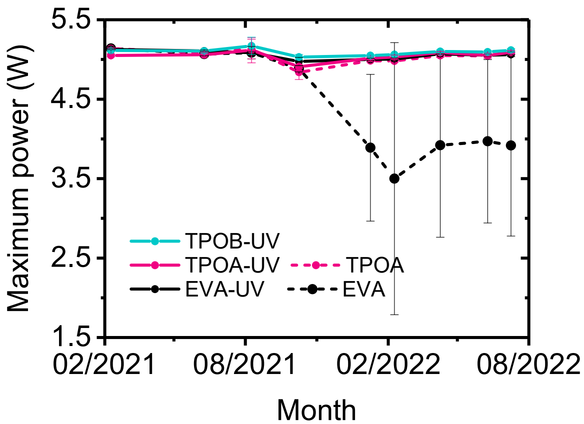
20 mini-modules installed outdoor

South 30°

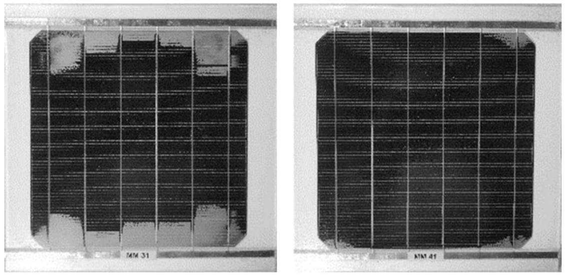
Ambiant

< 50 W.m^{-2} (300 - 400 nm)

17 months



Performances of outdoor SHJ mini-modules



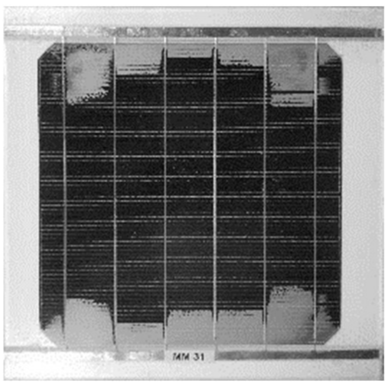
Outdoor aged SHJ mini-modules with EVA (left) and EVA-UV (right)

Delamination of mini-modules SHJ with EVA and EVA-UV

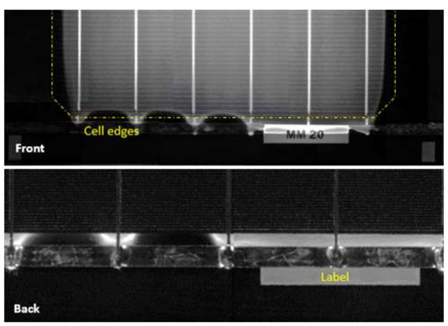
Worst degradation of EVA/TCO interface with EVA

UV absorbers prevent delamination

Conclusions



EVA mini-module aged outdoor



532 nm PL images

Mini-modules initial performances

Encapsulant	P_{max} (W)	I_{sc} (A)	V_{oc} (V)	FF (%)
EVA	5.10 ± 0.01	9.38 ± 0.01	0.736 ± 0.001	73.9 ± 0.2
TPOA	5.16 ± 0.01	9.43 ± 0.01	0.738 ± 0.001	74.2 ± 0.1
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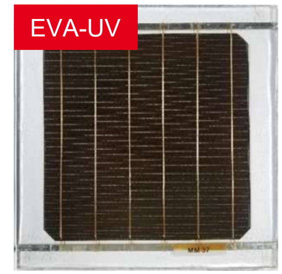
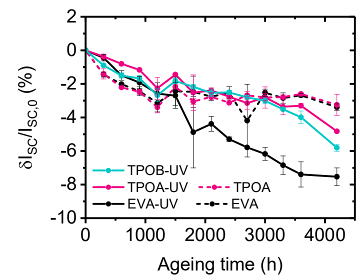
TPOB-UV	5.12 ± 0.01	9.34 ± 0.01	0.737 ± 0.001	74.3 ± 0.1

With UV absorbers	VS	Without UV absorbers
Delamination		Initial performances
532 nm PL		Yellowing
UV stable UV absorbers		UV proof SHJ

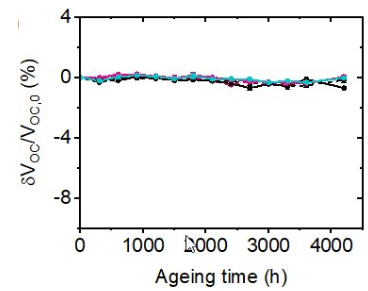
Thank you for your attention



EVA-UV mini-module aged in UV chamber



I_{sc} degradation of mini-modules aged in UV chamber



V_{oc} stability of mini-modules aged in UV chamber

On the behalf of the SMSP team from the DTS