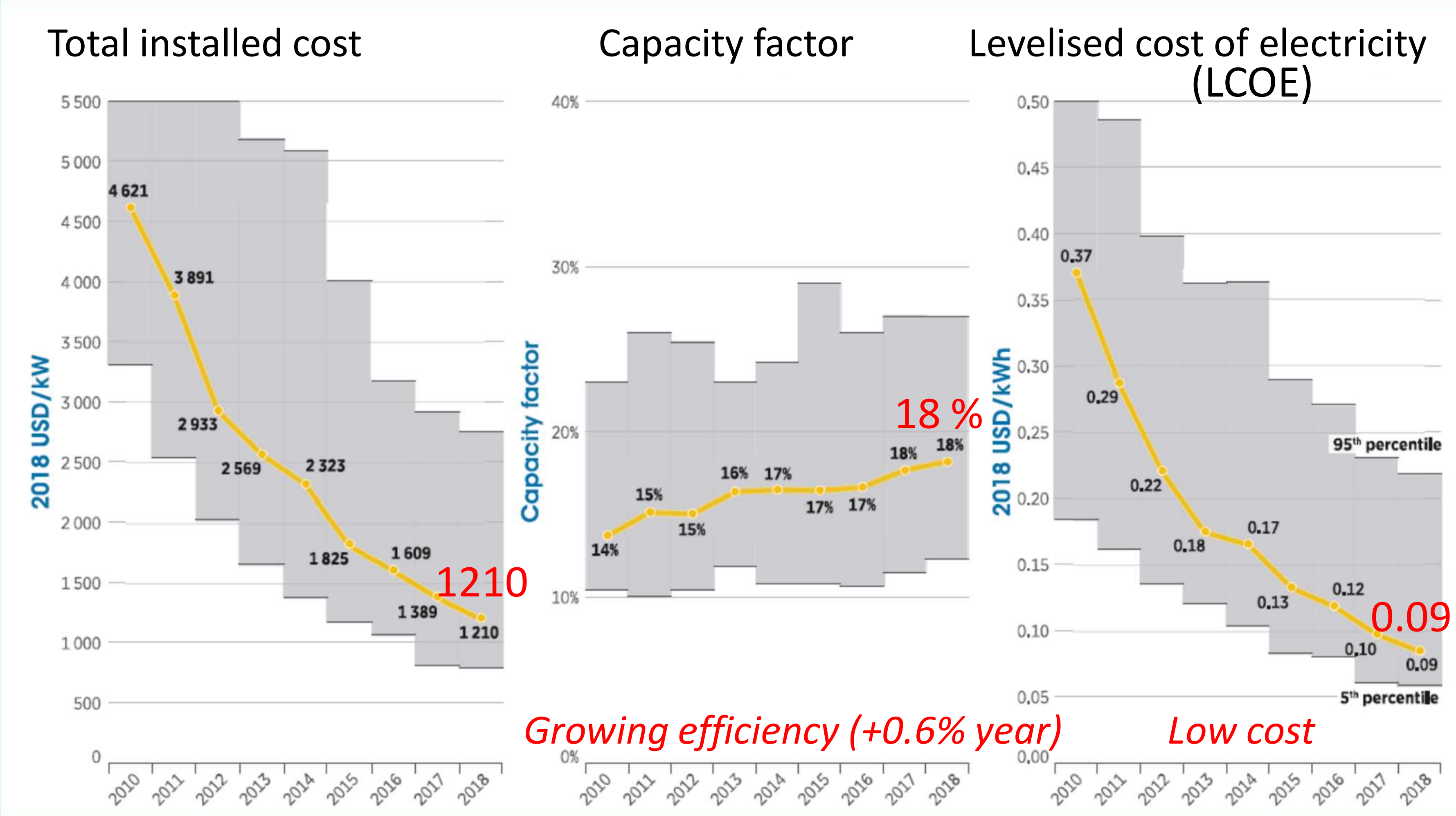
Corrosion & Solar Panels

Polina Volovitch, Jean-François Guillemoles,
Shanting Zhang, Alina Maltseva, Nathanaelle Schneider, Gunilla Herting, Inger Odnewall Wallinder

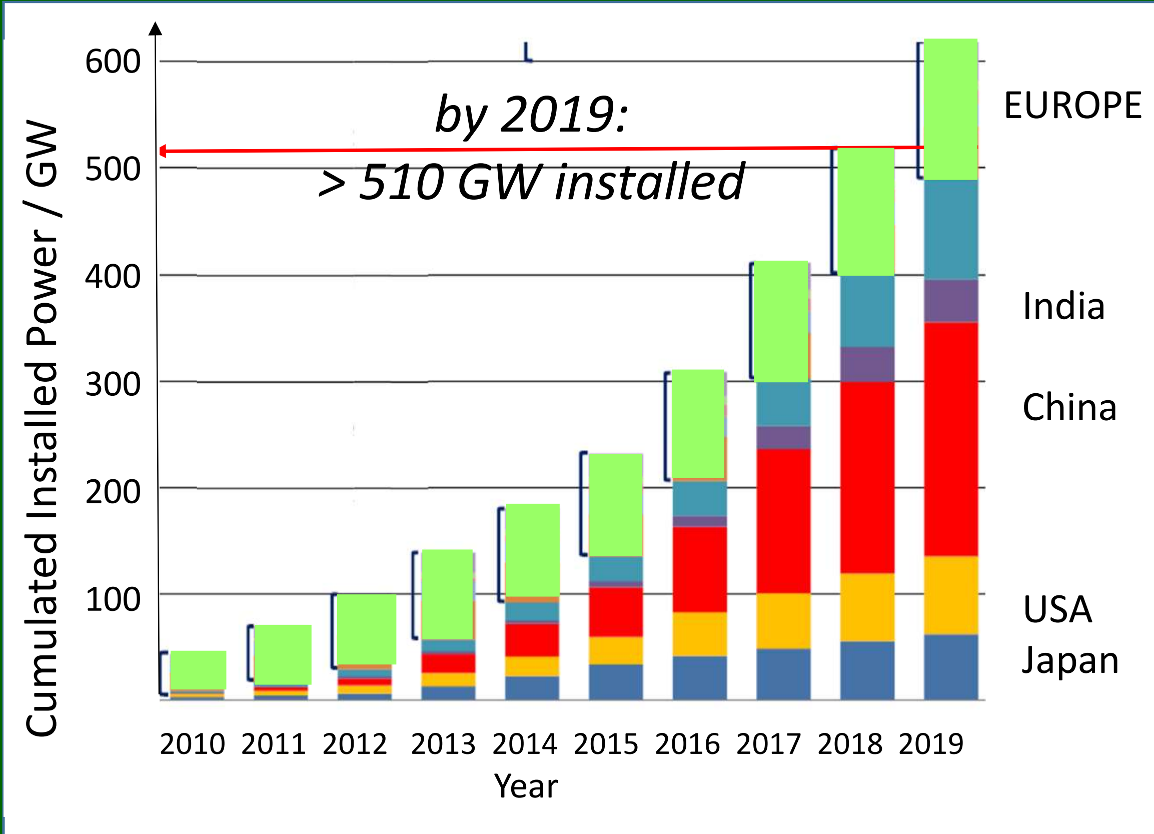
*polina.volovitch@chimieparistech.psl.eu

PhotoVoltaic (PV) technology: economical aspects



IRENA (2019), *Renewable Power Generation Costs in 2018*, International Renewable Energy Agency, Abu Dhabi.

PV technology: economical aspects



Industrial maturity

2.58 % of word electricity in 2018

Mostly centralized (>60%)

30 % annual growth

Durability standards

Loss in performance < 1 %/year

Warranty up to 25 years

Recycling

Source: Jäger-Waldau, A., PV Status Report 2019, doi:10.2760/326629

PV technology: stability issues

- Issues in bankability of the emerging technologies & impact on LCOE

$$LCOE\ \left(\text{€}/_{kWh}\right) = \text{€}/_{m^2}\ \ {m^2}/_{kW_c}\ \ {Wc}/_{W}\ \ {1}/_{h}\ \ \text{€}/_{\text{€}}$$

1. Production costs
2. Efficiency
3. Insolation & Capacity
4. Lifetime
5. Capital cost

LCOE increases 10% per 1% increase in degradation rate (data from NREL)

- Security

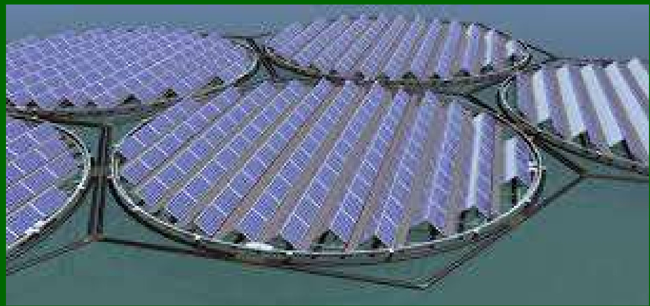
Long history of shortcomings wet reliability in PV

Active materials :Si, Cu_2S, a:Si, OPV, TCO, ….

… and systems : EVA, cables, backsheets, metallic contacts (Ni, Al, Cu, Ag…)….

Environmental conditions for PV systems

- Farms
- Rooftop
- Isolated, micropower
- Float, roads, agriPV, …



Hubble solar cells, 8.25 years in space

Needs and opportunities in reliability research for PV

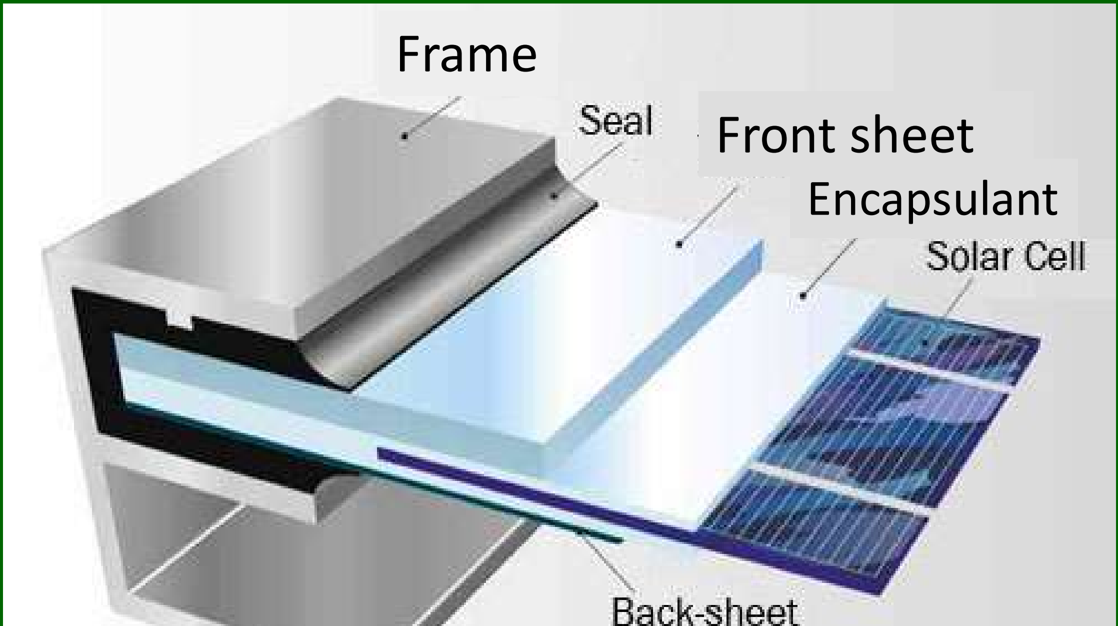
- Existing materials and components to reference (benchmark): propose and validate relevant tests and relate results of the tests with degradation mechanisms
  => improve reliability of existing systems

- Existing materials and components: projections for warrantee returns => propose in advance repair solutions or replacement

- New materials and components: propose/validate/use relevant tests and relate results of the tests with degradation mechanisms

  => improve reliability of new materials and systems

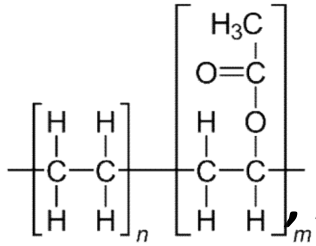
PV technology materials: materials



https://www.riteksolar.com/eng/p2-solar_modules.php

*Frame: **Al** alloys (6xxx extruded)*

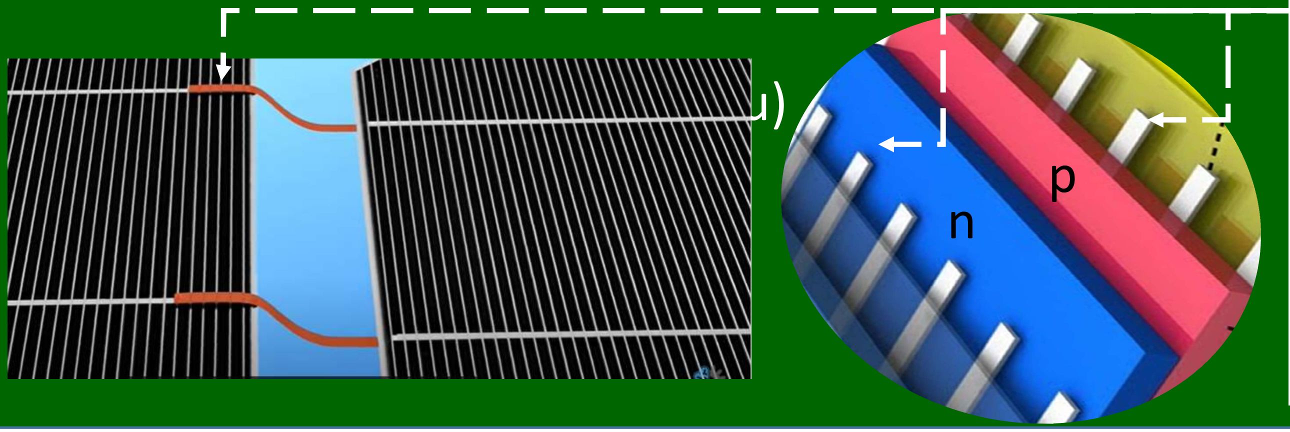
Front sheet: glass

*Encapsulant: **EVA***  ***, PVB***

(70% of the market)

*Back-sheet: **TPT** (Tedlar – PET-Tedlar) ,*
*TAT (Tedlar-**Al**-Tedlar), …*

Tedlar© – PolyVinileFluoride (PVF)



*metallic conductors: **Ag, Al, Mo, Cu** …*

Semiconductors:
***Si** (90 % of the market)*
***$Cu(In,Ga)Se_2$**, etc.*
*Passivating layer: **Al_2O_3, SiN**, …*

Why study chemical effects on durability?

Sun (UV)

Wetness (H_2O)

T°C

High Tension

Mechanical stress (flow, scratch, wind…)

Oxidants (0_2, 0_3, H_2O_2, SO_4^{2-}, …)

Dust (particles)

Pollutants (Cl^-, NH_4^+, CH_3COO^-, …)

Corrosion
Polymer degradation
Delamination

Water accumulation

Shadow

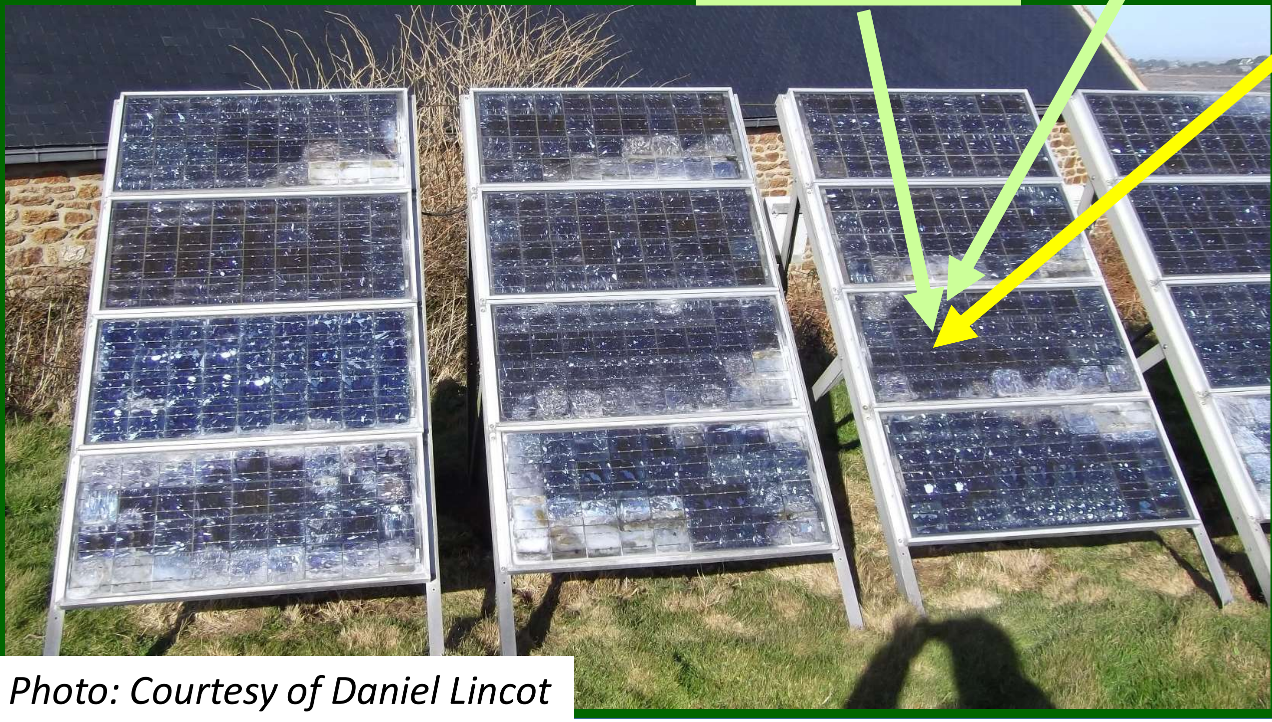
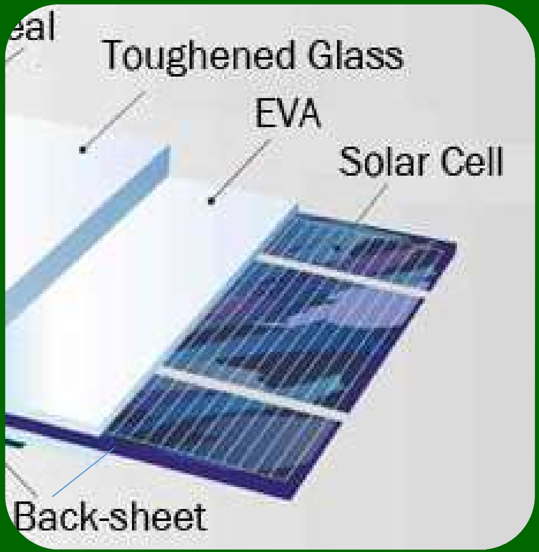
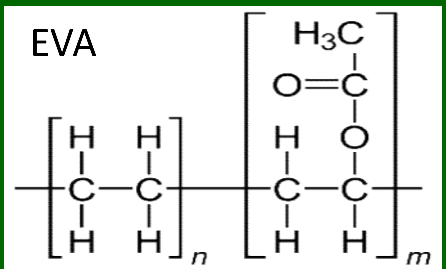
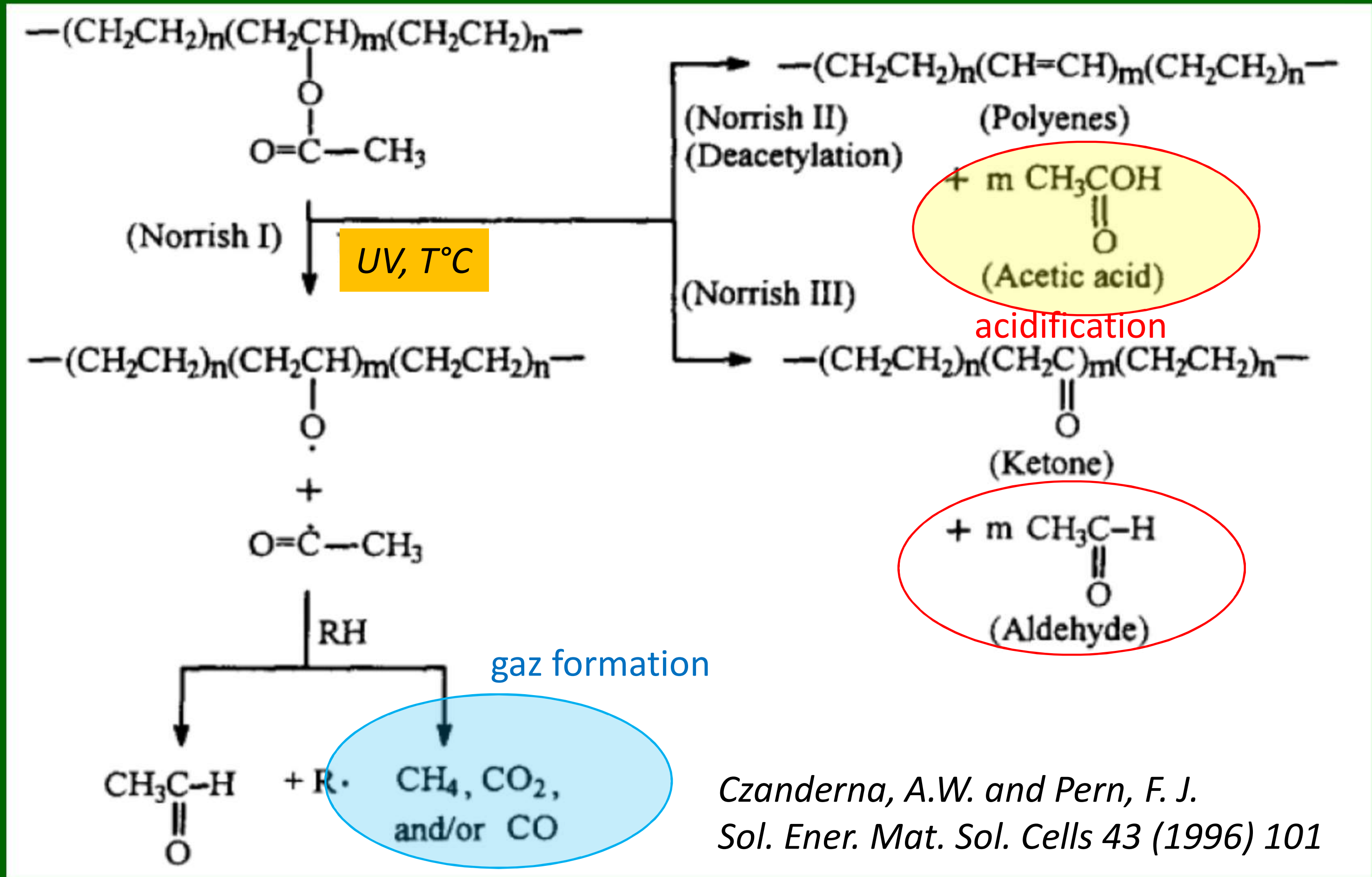


Photo: Courtesy of Daniel Lincot

Chemical effects: chemical modification in confined zone ?





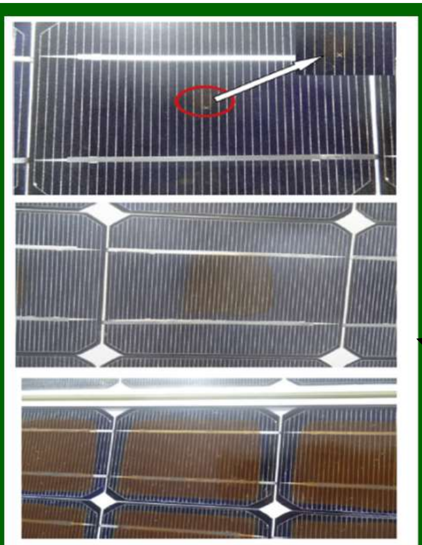


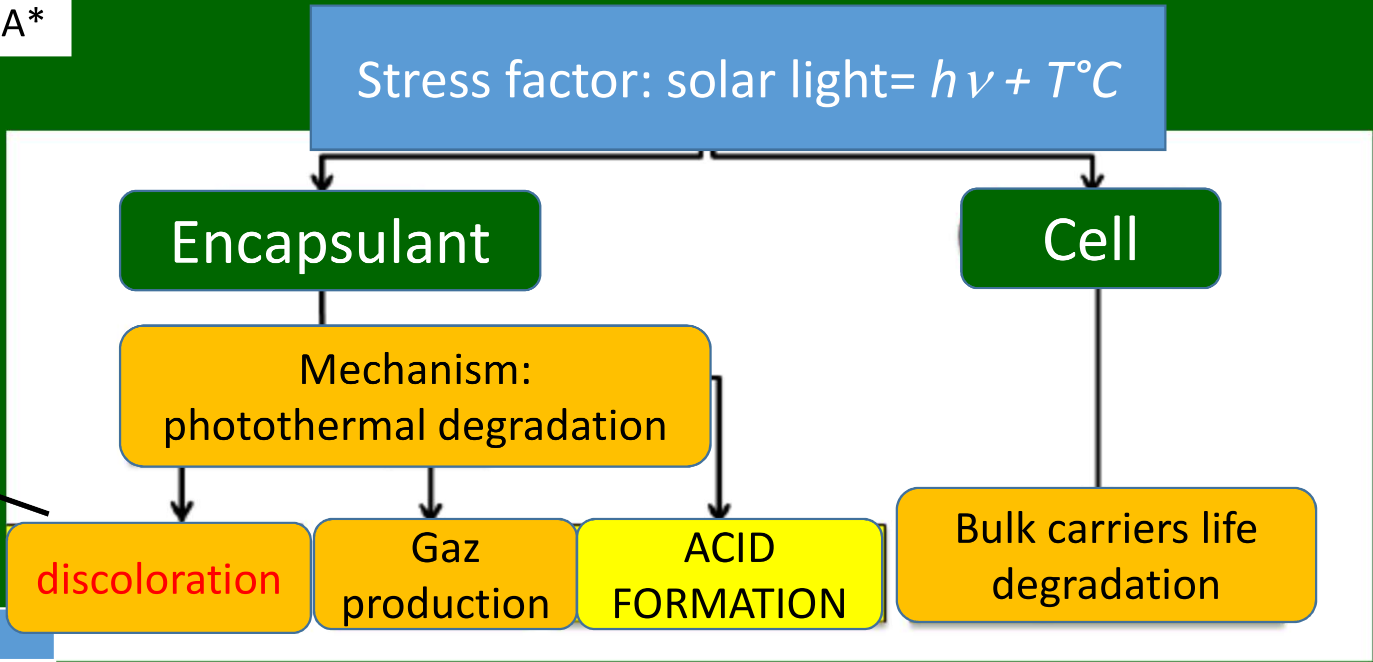
Czanderna, A.W. and Pern, F. J.
Sol. Ener. Mat. Sol. Cells 43 (1996) 101

Polymer degradation → Delamination → Corrosion

Chemical effects: what can arrive in confined zone ?

EXAMPLE: discoloration after 12 years in SAHARA*





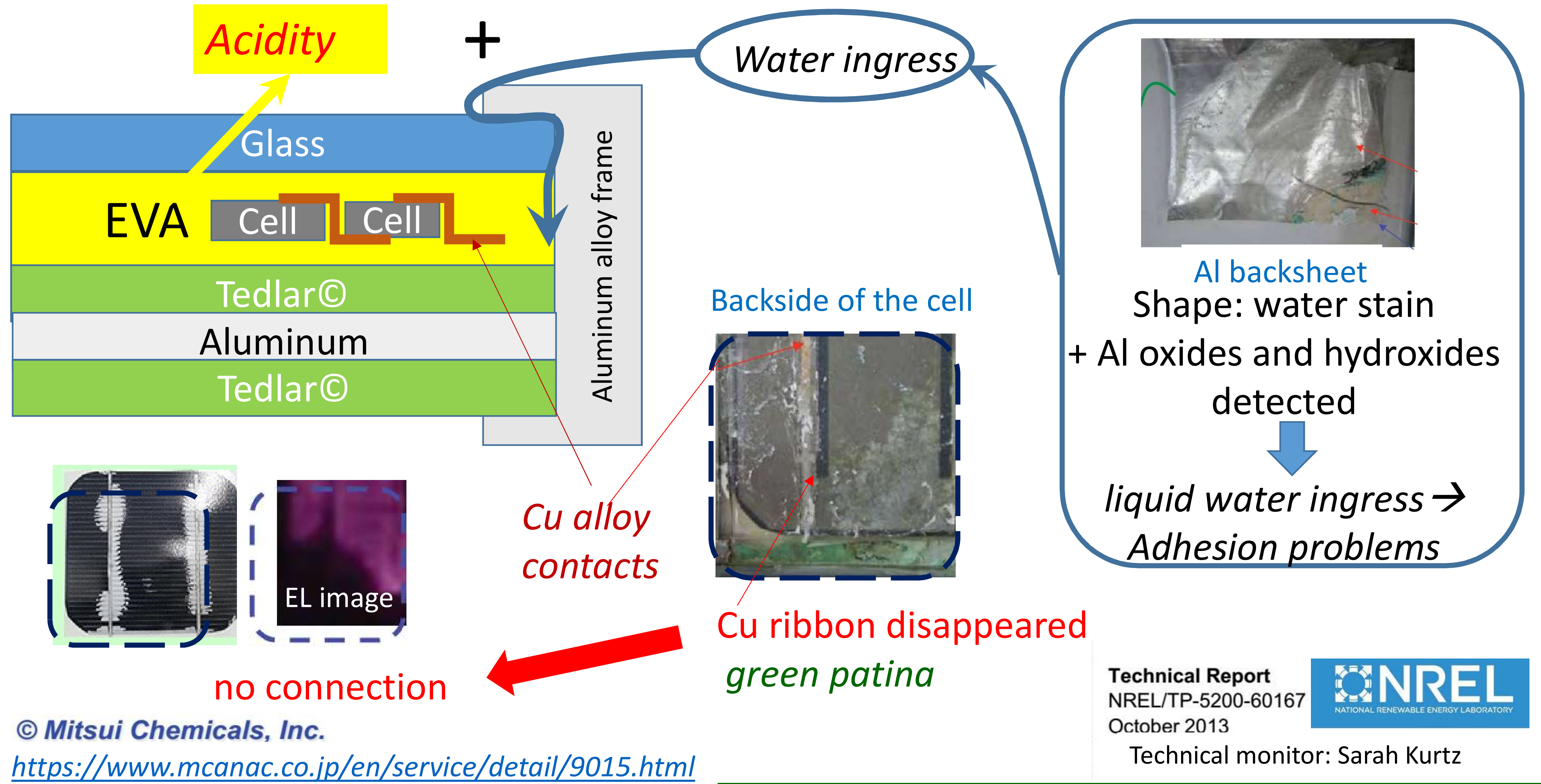
Defect	% affected
EVA Discoloration encapsulant	100 %
Busbar corrosion	50 %
AR coating deterioration	40 %
Solder bond degradation	3 %
Delamination	6-7%
Glass breakage	< 2%

D. WU et al. in. Proc. 8th Photovolt. Sci. Appl. Techn. Conf.(PVSAT-8), Northumbria University, Newcastle upon Tyne, 2-4 April 2012, pp. 177 - 180

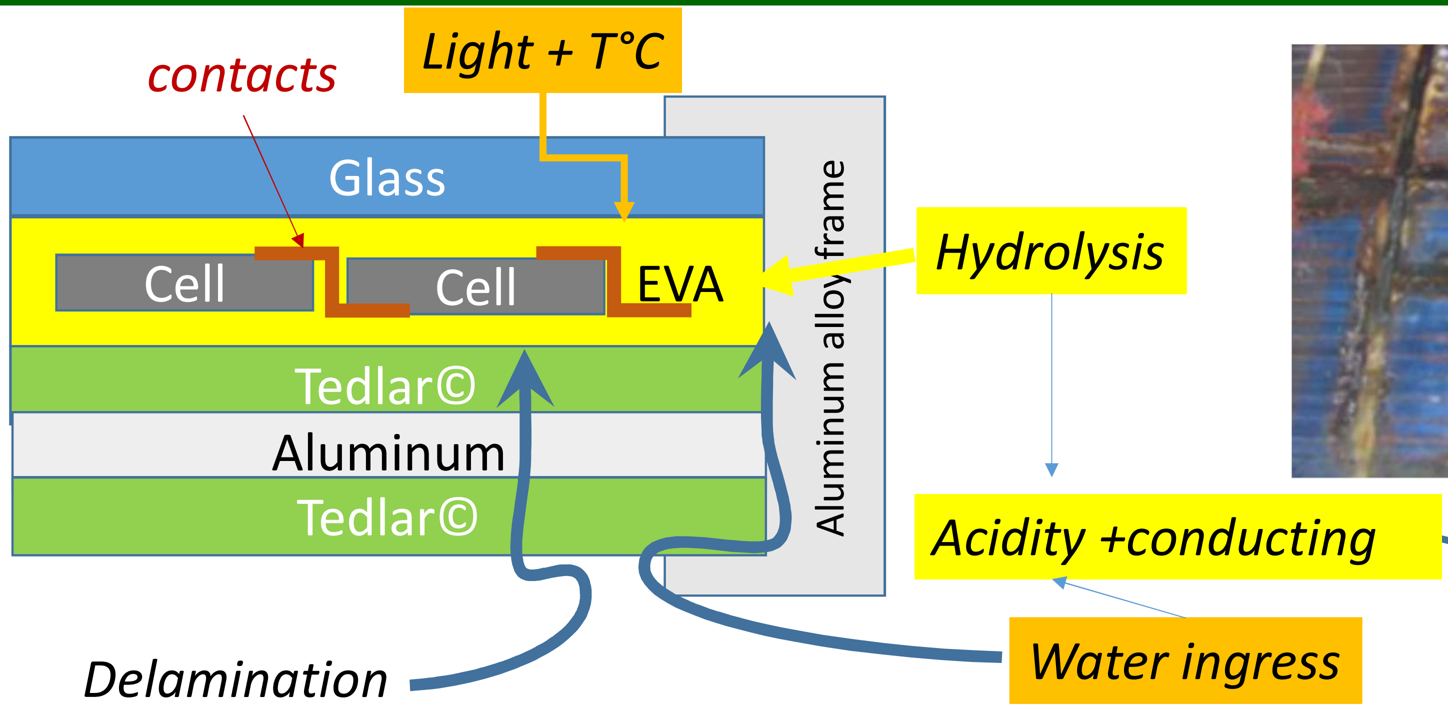
+ all species accumulate in confined zone

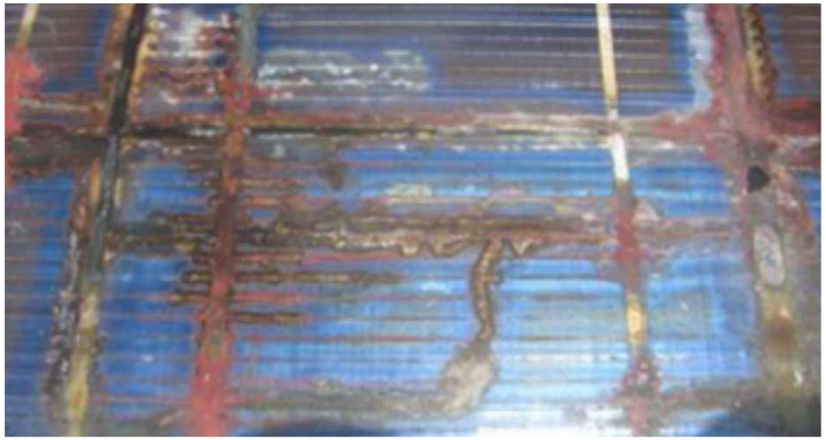
* ©A. Bouraiu et al. Energy 132 (2017) 22

Chemical effects: what can arrive in confined zone ?



Encapsulant effects: consequences on module performance

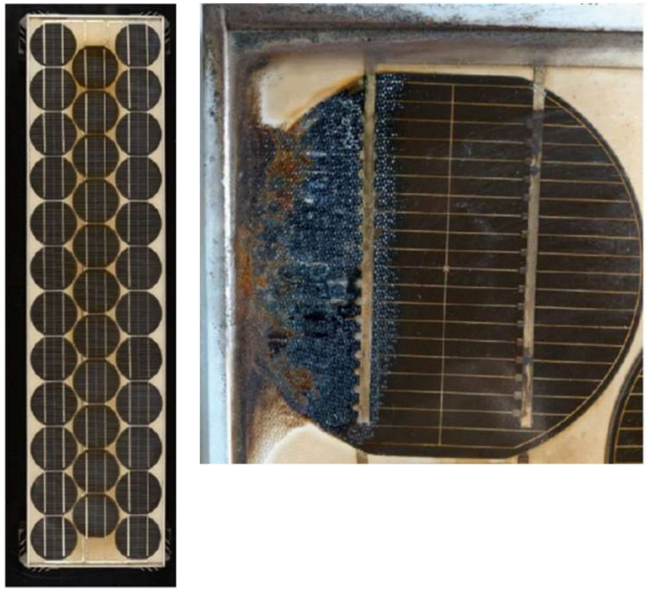




corrosion-> Rs decrease
leakage current-> Irs increase

*WU, D. ... et al., 2012. Proc. 8th Photovolt. Sci. Appl. Techn. Conf.(PVSAT-8)

Observations from TISO-10-kW plant (Lugano, Switzerland) after 35 years [1]



Photos: curtesy of Allessandro Virtuani

Atmosphere inside the module:
indoor atmospheric corrosion?
CH_3COO^-, $CHCOO^-$

EVA encapsulated (expected formation of acetic acid):

-0.7 % performance loss per year!

PVB encapsulated (degradation products not studied):

degradation rates of -0.2% per year, which corresponds to a loss in performance below 10% over 35 years.

[1] *Annigoni, E. , Virtuani, A., Caccivio, M., Friesen, G; Chianese, D, Ballif, C. Progr. Photovolt. Res. Appl. 27 (2019)760, DOI: 10.1002/pip.3146*

Ageing tests: what is named climate specific in PV?

- ✓ Climate specific humidity and temperature changes (DH)*

  (for instance IEC 60068-2-30:2005)
- ✓ UV illumination
- ✓ Combined damp heat + UV
- ✓ Potential induced degradation-delamination (IEC TS 62804-1-1:2020)

Field exposed module

Chemical effects of the atmosphere rarely considered

- ✓ NaCl – salt spray test (IEC 61701 standard)
- ✓ Ammonia test (IEC 62716:2013)

Very limited number of mechanistic studies

Corrosion inside laminate in salt spray!

*G. Eder et al. *Prog Photovolt Res* 934 *Appl*. 2019;**27**:934–949 DOI: 10.1002/pip.3090

Chemistry of atmospheric corrosion still stays relevant for PV!

Indoor:
CH_3COO^-, $CHCOO^-$

Typical for industrial atmosphere

Outdoor:

CO_2, O_3, NO_2, $H_2S \rightarrow SO_2 \rightarrow SO_4^{2-}$, Cl^-, Ca^{2+}, Mg^{2+}, Na^+, NH_4^+, H^+

0.7–150.4 mg m^{-2} day^{-1}

0.4–760.5 mg m^{-2} day^{-1}

Typical for rural atmosphere

Typical for marine atmosphere

Rain River Fog Ocean Aerosol Particle

10^{-3} → *Ionic force* $I = 1/2\ \Sigma m_i[Z_i]^2$ → 10

[1]C. Leygraf, I. Odnewall Walinder, J. Tidblad, T. Graedel, Atmospheric Corrosion, Wiley.

[2]D. Knotkova, K. Kreislova, in. WIT Transactions on State of the Art in Science and Engineering, 28

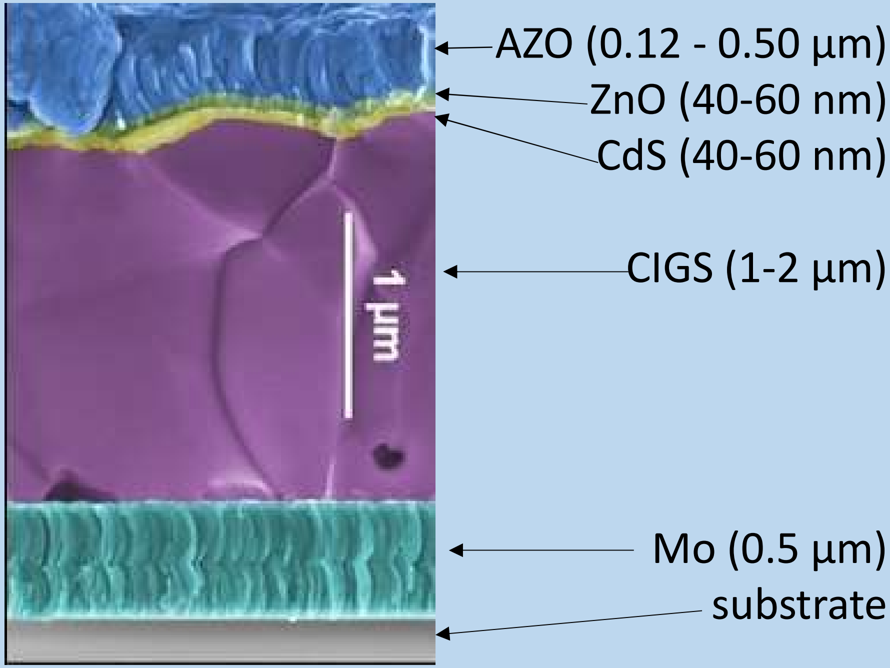
Thin (flexible) cells: stability of encapsulants and thin oxide layers

Glass protection is impossible…

New encapsulation solutions are needed !

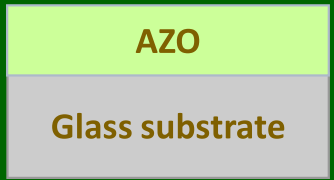
"Good" encapsulation often qualified by 1000 h Damp Heat (DH) test

Typical structure of thin layer cell: $Cu(In, Ga)Se_2$

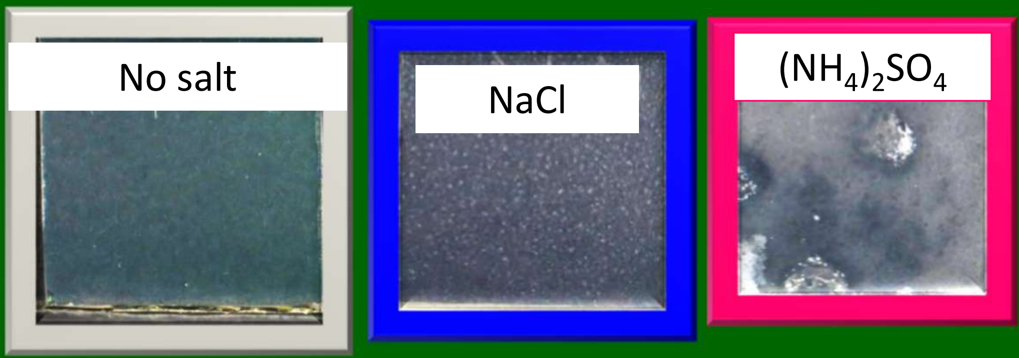


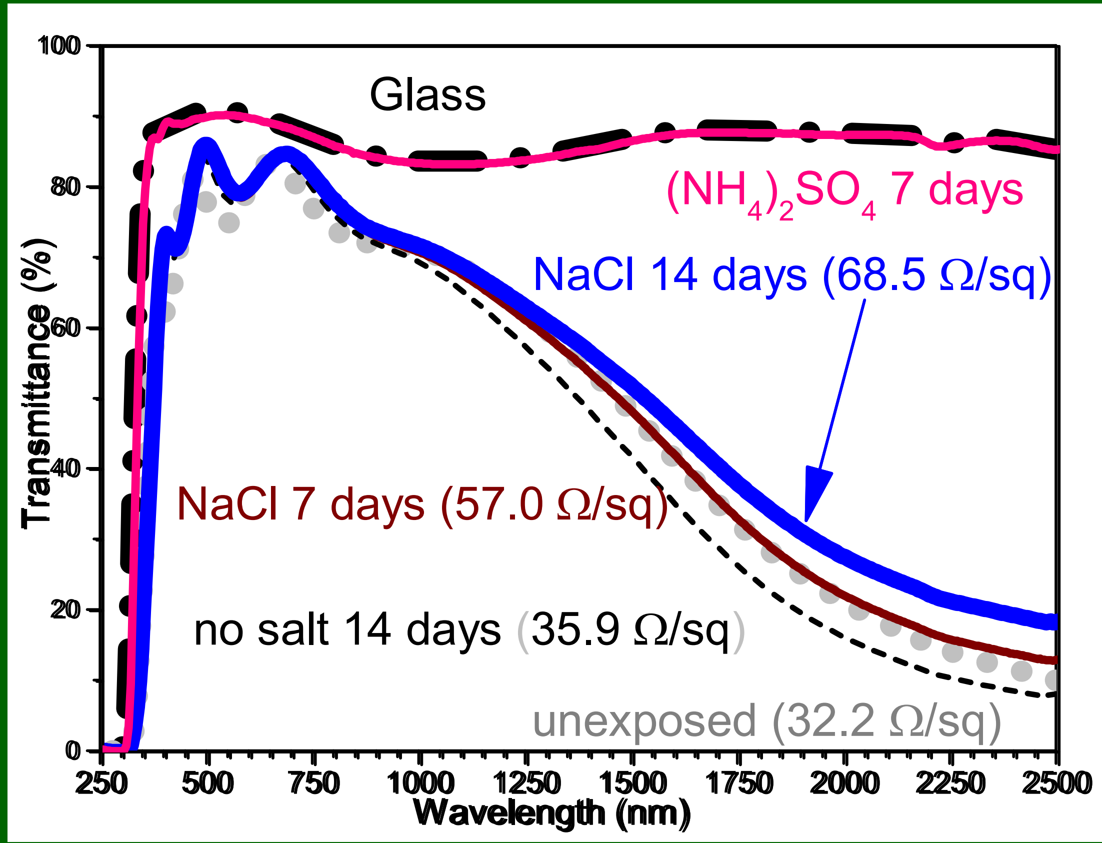
Effect of atmosphere: AZO layer w/o encapsulation

<0.1 µm thick Al-doped ZnO (AZO)



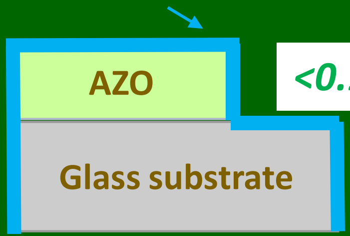
After 14 days of cyclic test humitidy-T°C test w/o and with selected salts





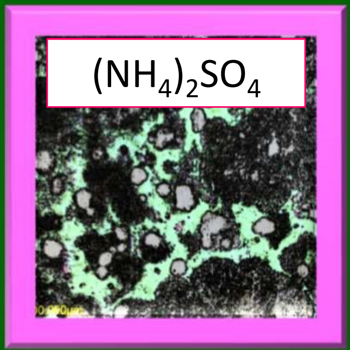
Effect of atmosphere: AZO layer with new encapsulation

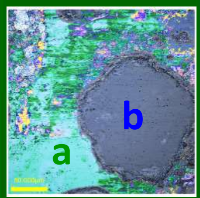
Encapsulate qualified by 1000 h damp heat test

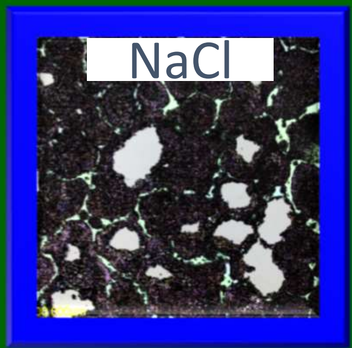


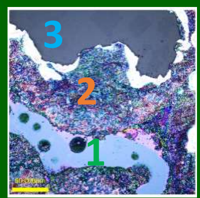
<0.1 µm thick Al-doped ZnO (AZO)

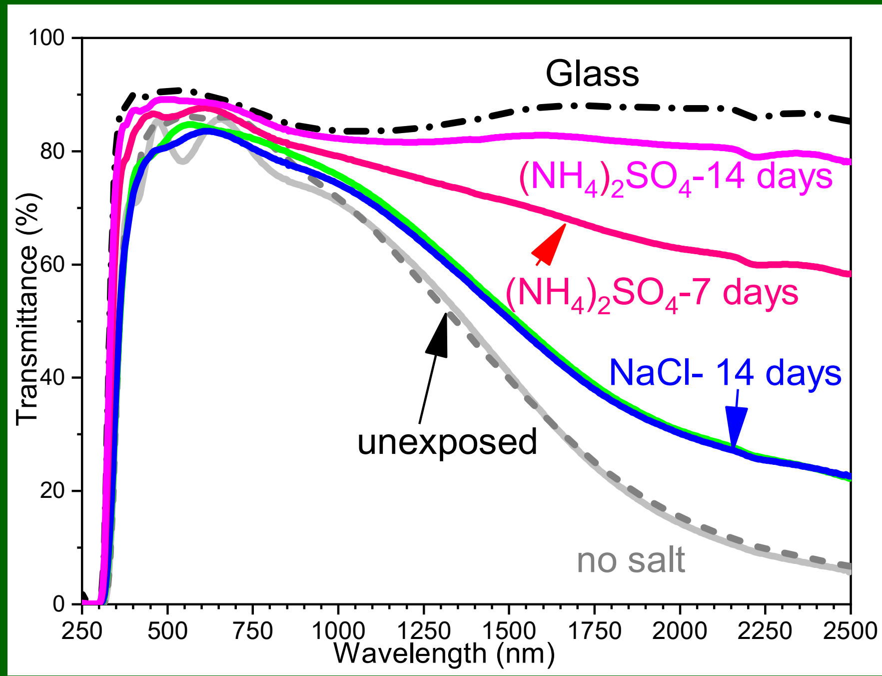
After 14 days of cyclic test humitidy-T°C test
w/o and with selected salts











Atmospheric chemistry cannot be neglected
for both, non-encapsulated and encapsulated systems!

Opportunities for corrosion scientist in PV research

Corrosion is one of the key degradation mechanisms in modules responsible for power loss

Corrosion scientist can help to answer numerous questions

1) What are the main corrosion mechanisms? How these mechanisms are activated ?

2) What are the reactants and the reaction products? How identify them in modules?

3) How corrosion and chemical degradation lead to functional failure?

5) How to characterize the system (chemistry, morphology, performance) in practice?

6) How to model the degradation and to validate the models in various field environments ?

7) How to improve the system durability?

Durability is important factor for PV energy costs

Chemical effects cannot be neglected in durability studies
for both, non-encapsulated and encapsulated systems!

Corrosion science can offer a complementary look ….
Let us try to explore!

EURO CORR SEPTEMBER 6-10, 2020 BELGIUM BRUSSELS
THE ANNUAL CONGRESS OF THE EUROPEAN FEDERATION OF CORROSION

eurocorr.org

Thank you for your attention!

Questions?

Chimie Paris ParisTech | PSL

IPVF INSTITUT PHOTOVOLTAÏQUE D'ILE-DE-FRANCE