BARRIER COATINGS FOR NEXT GENERATION FRONT SHEETS FOR ORGANIC PHOTOVOLTAICS

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BOOSTER

Fraunhofer FEP

ARMOR

DuPont Teijin Films™

Fraunhofer Institute for Organic Electronics, Electron Beam and Plasma Technology FEP

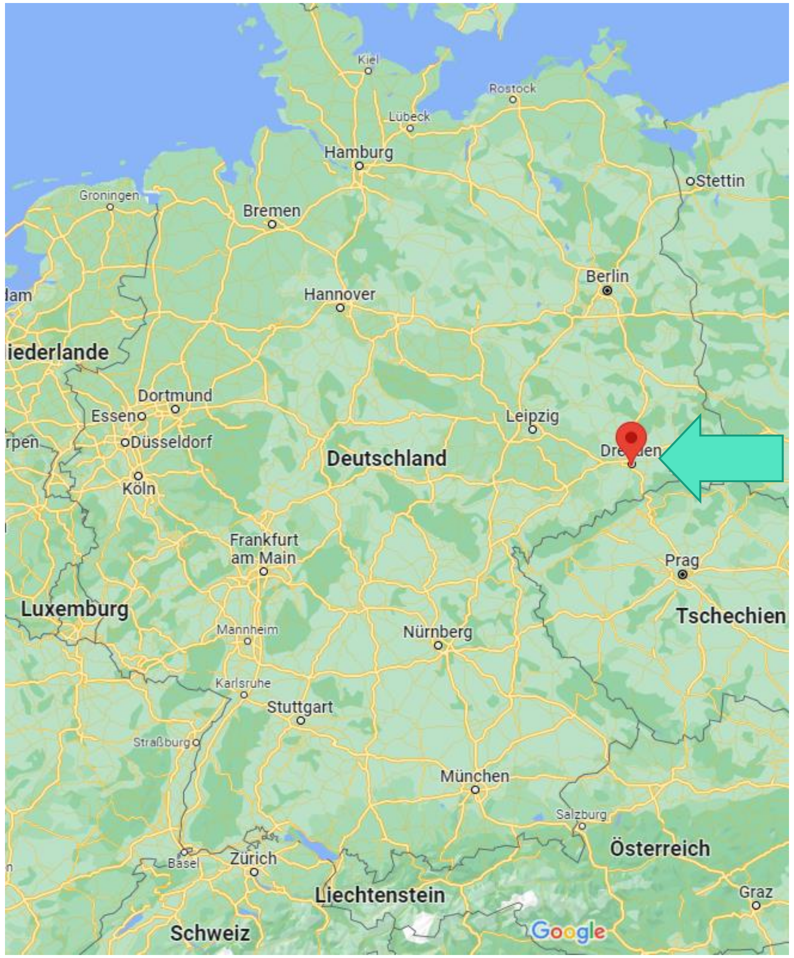
Facts & Figures

Employees	202
Total budget	28.85 M€
Industry returns	11.5 M€
Public funding	9.75 M€
Basic funding	7.6 M€

2021

Director

- Prof. Dr. Elizabeth von Hauff



Location

- Dresden / Saxony / Germany

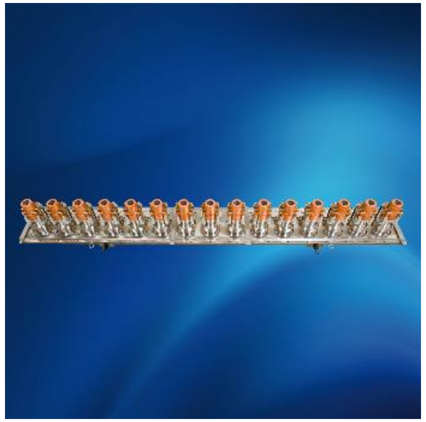
Core Competencies

ORGANIC ELECTRONICS

ELECTRON BEAM TECHNOLOGIES

PLASMA-ACTIVATED LARGE AREA AND PRECISION COATING

ROLL-TO-ROLL TECHNOLOGY



TECHNOLOGICAL KEY COMPONENTS

IC-DESIGN

BOOSTER Project

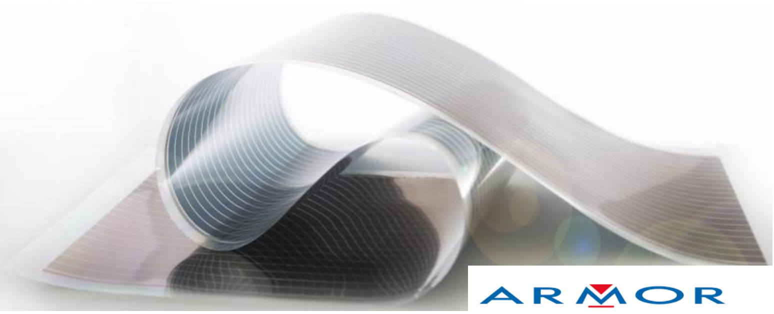
Project Aims & Facts

- BOOSTER – **B**oost **O**f **O**rganic **S**olar **T**echnology for **E**uropean **R**adiance
- Target deployment of OPV to the building applied photovoltaic (BAPV) market
- OPV technology address problematic of global energy production with Eco responsible approach
- OPV manufacturing features low energy-payback-time
- BOOSTER aims at bringing OPV technology to TRL7

BOOSTER

European Union

Europe funds Saxony.
EFRE
European Regional Development Fund



BOOSTER project start	September 2020
BOOSTER project duration	48 month
BOOSTER project budget	8.2 M€ (EU contribution: 6.1M€)
Project call	Next generation of thin-film PV technologies

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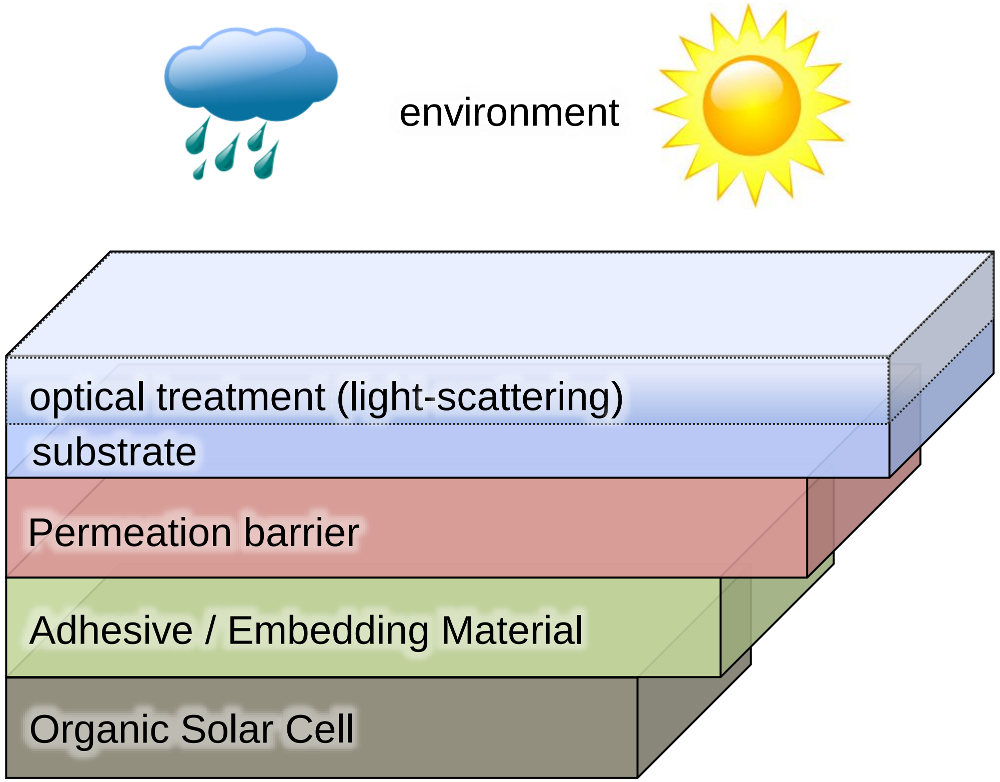
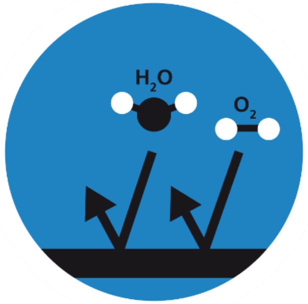
Project Partners

Next generation front sheet

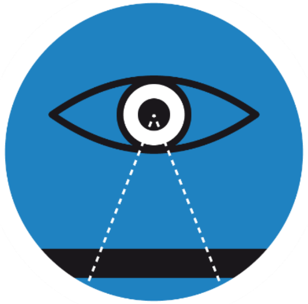
Overall Challenge for next generation frontsheet





humidity and oxygen resistance

blocking UV-radiation



Optical transparency

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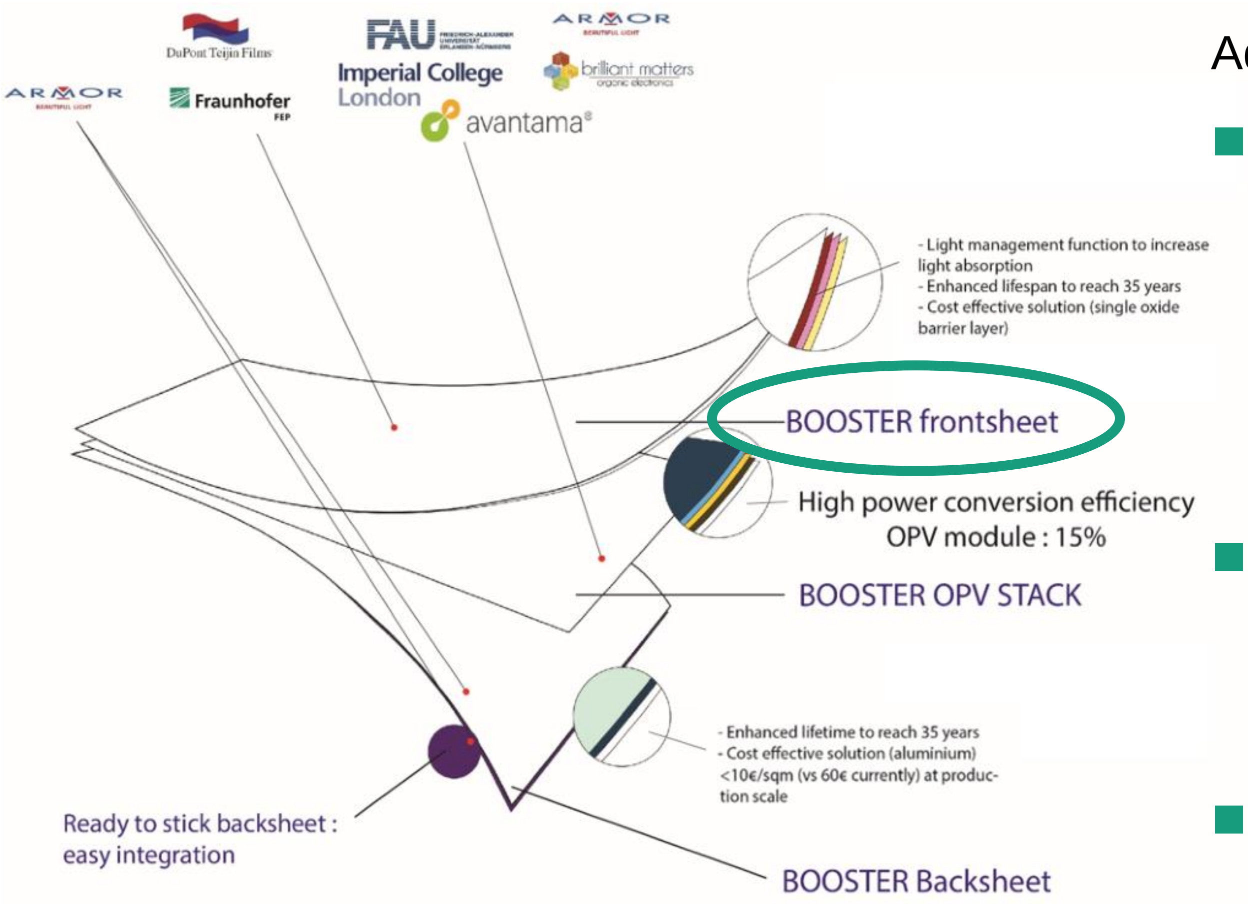
Objectives for next generation front sheet (BOOSTER WP3)



Advance the encapsulation frontsheet:

- Enable **35 yrs. stability in outdoor use** for polyester films by integrating:
  - Ultraclean surface
  - UV-protection + hydrolysis stability
  - Light-scattering
- Improve outdoor stability and roll-to-roll processes of OPV grade gas barrier films for **35 yrs lifetime and 35% reduced manufacturing cost**
- Determine test protocols for accelerated ageing and durability testing **in reasonable and industry suited verification times**

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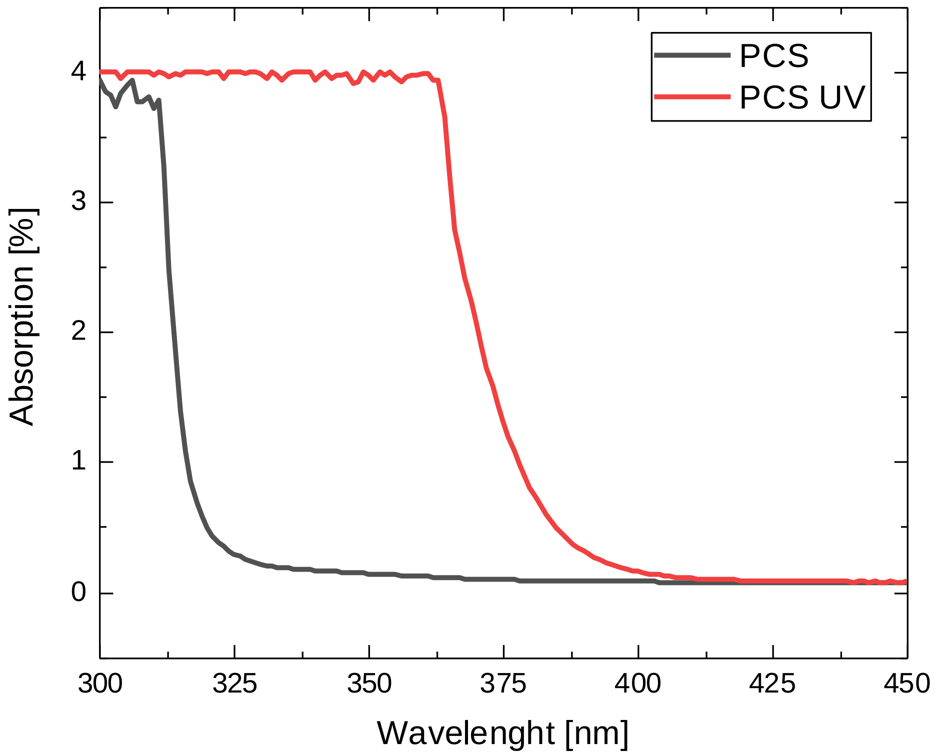
Intended aims for next generation front sheet in BOOSTER project

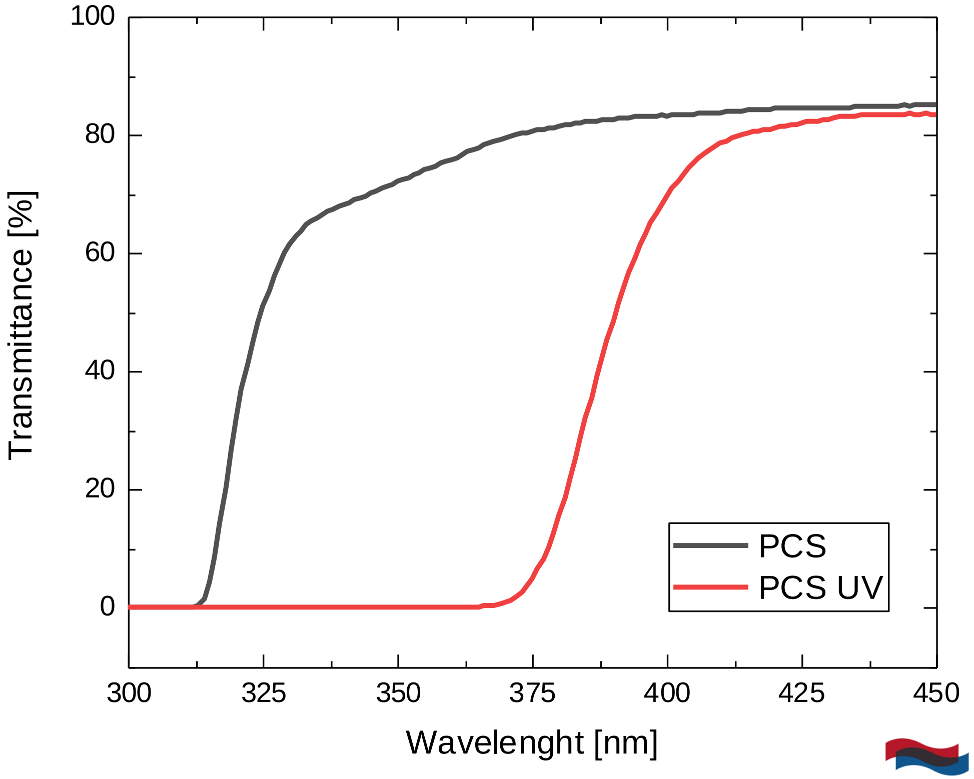
Item	Min	Max	Optimum
Transparency	**80 %**	**-**	**90 %**
UV-cut-off	**375 nm**	**380 nm**	**380 nm**
Transparency at 405 nm	**70 %**		**85 %**
Thickness of frontsheet	60 µm	200 µm	125 µm
Mechanical flexibility (bending radius)		10 cm	5 cm
Max. Shrinkage	-	< 0.3 %	< 0.2 %
Water vapor transmission rate	**-**	**< 10^{-4} g/(m²d)**	
Oxygen transmission rate		< 0.1 cm³/(m²d bar)	
Max. OPV PCE loss in 3500 h Damp heat test (85°C / 85%)	**-**	**< 20 %**	**0 %**
Surface energy	45 nN/m		
Interfacial adhesion	6 N/cm		>10 N/cm

Substrate Material

Development UV absorbing films and…

- PCS – peelable clean surface – 100 µm (+ 25 µm protective liner Film)
- PCS UV - UV absorption curves: With cut off wave length ~ 380 nm
  - ➢ 70 % Transparency at 405 nm - still allowing epoxy to be cured





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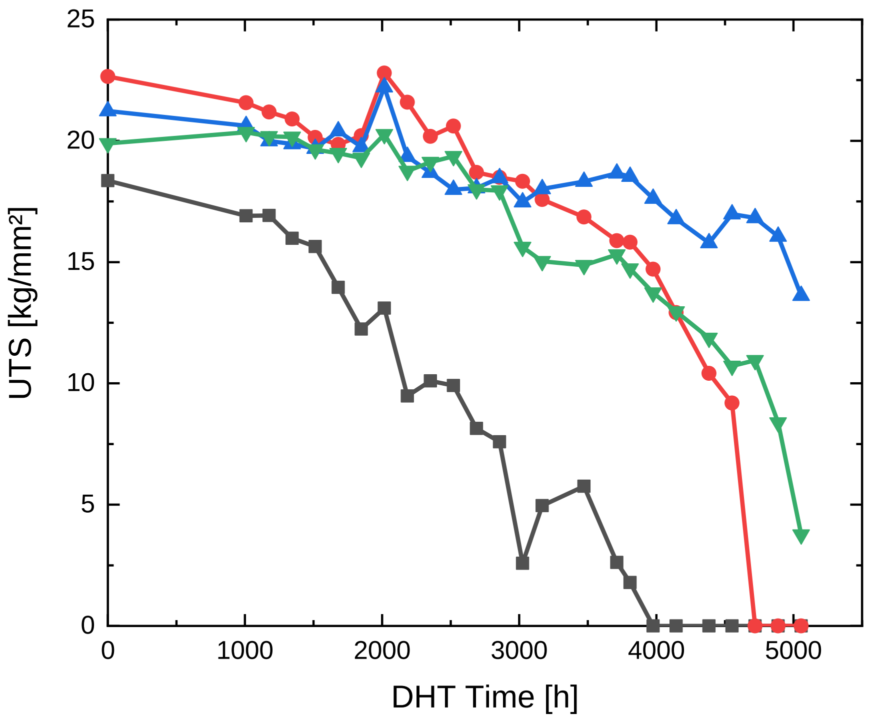
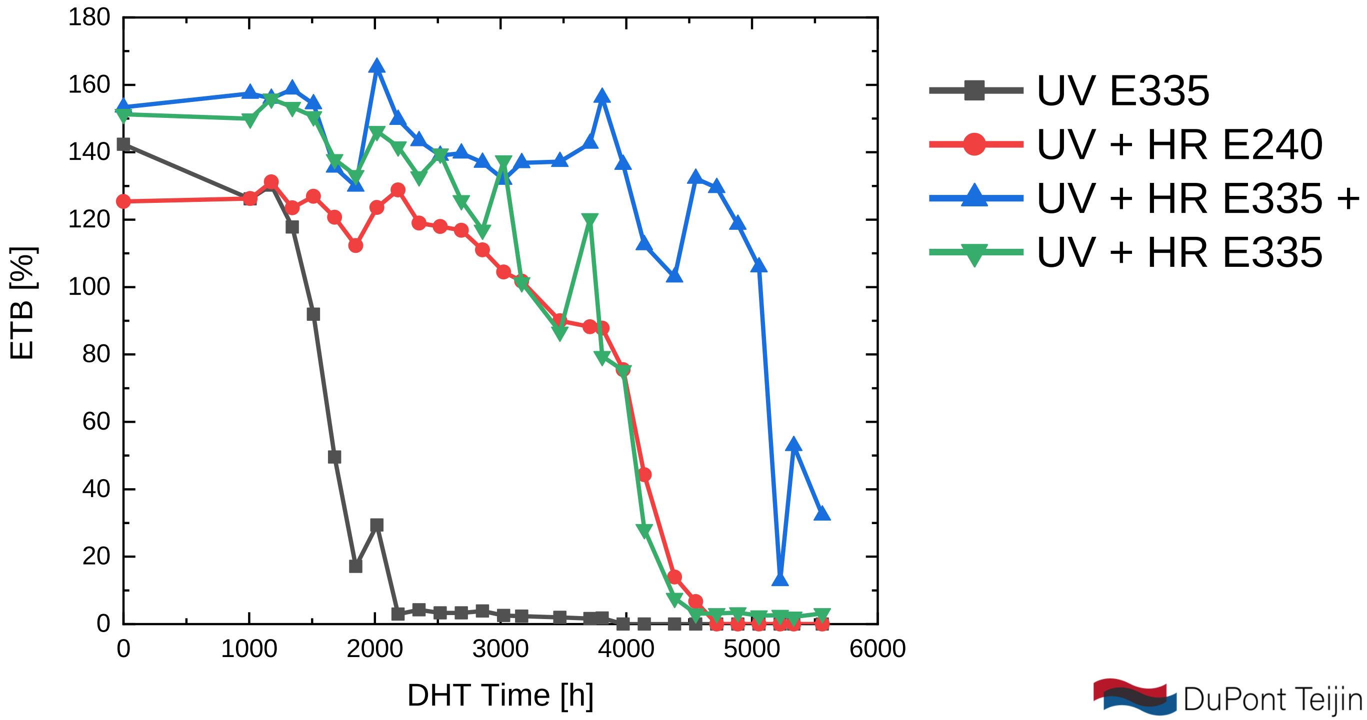
… and Hydrolysis stabilized film

- PCS UH - UV and Hydrolysis stable films with special additives
- DHT 85°C/85 % r.h. test – extended life time with HR from 3000 to > 5000hrs
- Material from pilot line - Additional improvement possible with production line manufacture





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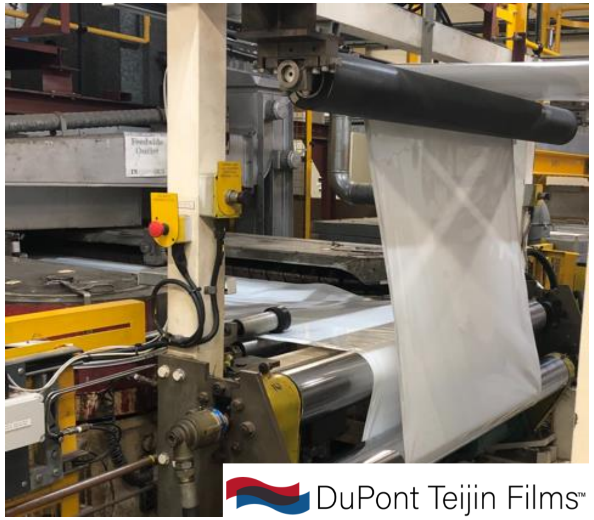
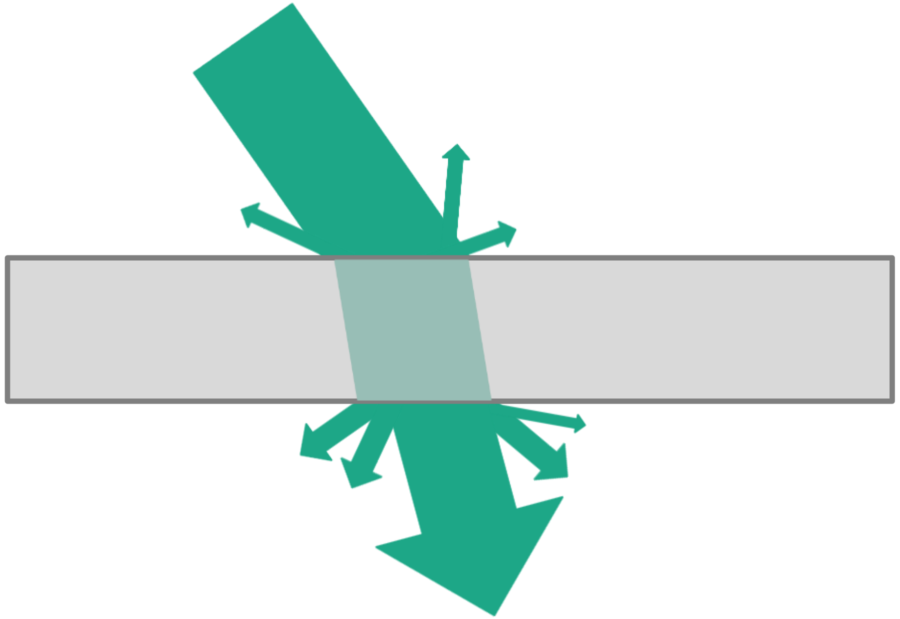
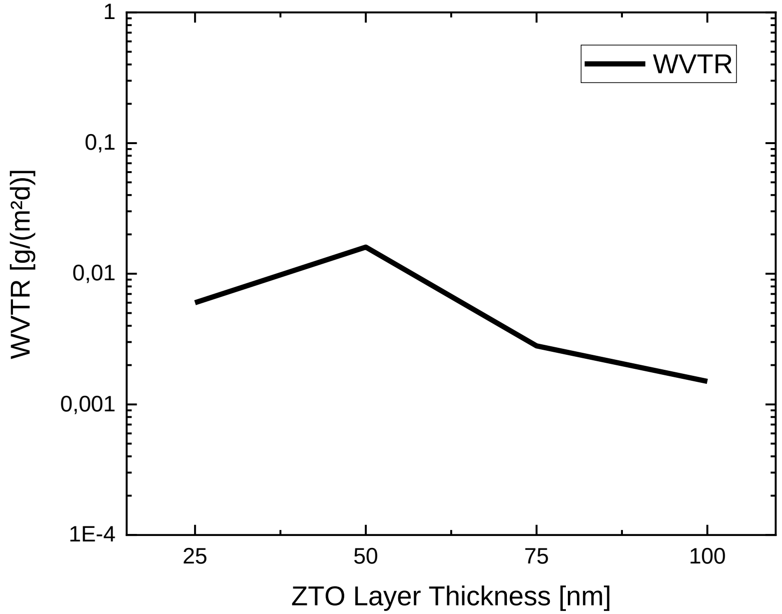
Next Step: Light scattering surface



- Increase efficiency by directing part of scattered light to OPV cell
- Ideas:
  - Add of light scattering particles to substrate material (particles can damage the barrier)
  - Structured hard coat

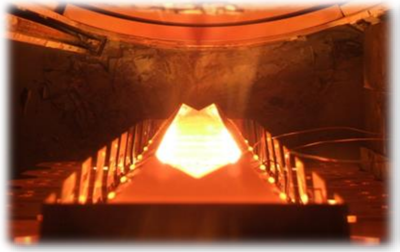


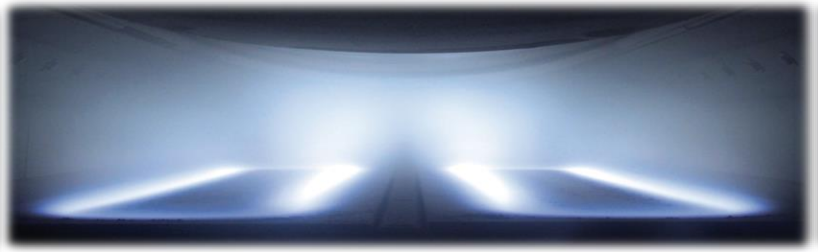


Coating Technologies

Vacuum technologies for gas barrier coatings

Technology	high rate evaporation	reactive sputtering	PECVD	atomic layer deposition
productivity [m/min]	600	0.5 … 4	≤ 1	0.1 nm / cycle
materials	SiO_2, Al_2O_3	ZTO, SiO_2, Al_2O_3	Si_3N_4, SiO_2, SiO_xC_y	Al_2O_3, TiO_2
typical layer thickness [nm]	5…20	10 … 300	100 … > 1000	15 … 25
effective WVTR [g/(m²d] … depending on substrate	> 0.5	≤ 10^{-3}	10^{-5} ….. 1	< 10^{-3} … 10^{-5}
status and perspective	large area roll-to-roll	large area roll-to-roll commercially available	depending on plasma source	roll-to-roll pilot lines < 10^{-3} g/(m²d)





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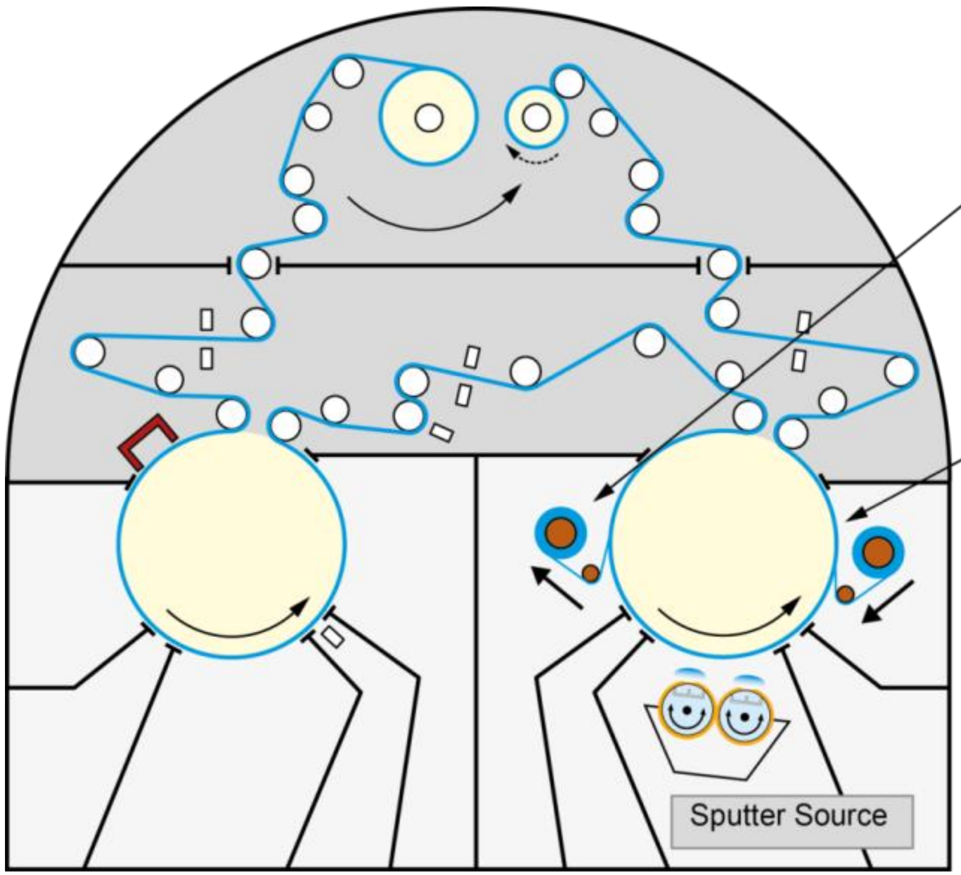
Protective films

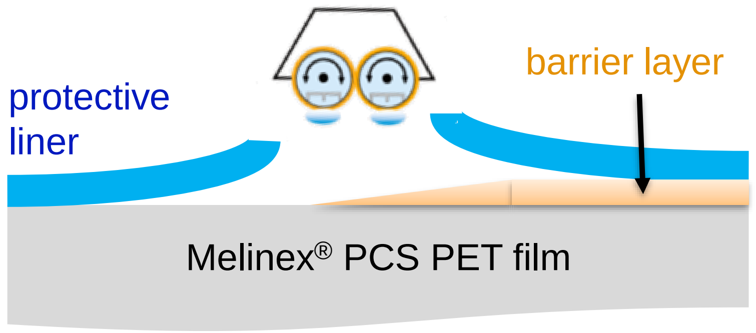


Pilot web coater coFlex600

Patent pending

aim:

- PCS – peelable clean surface
- protect film surface until coating
- instantly add another protective liner film (PL) after coating
- liner adheres well to the coating and gives a robust barrier solution
- liner can be considered as an encapsulant



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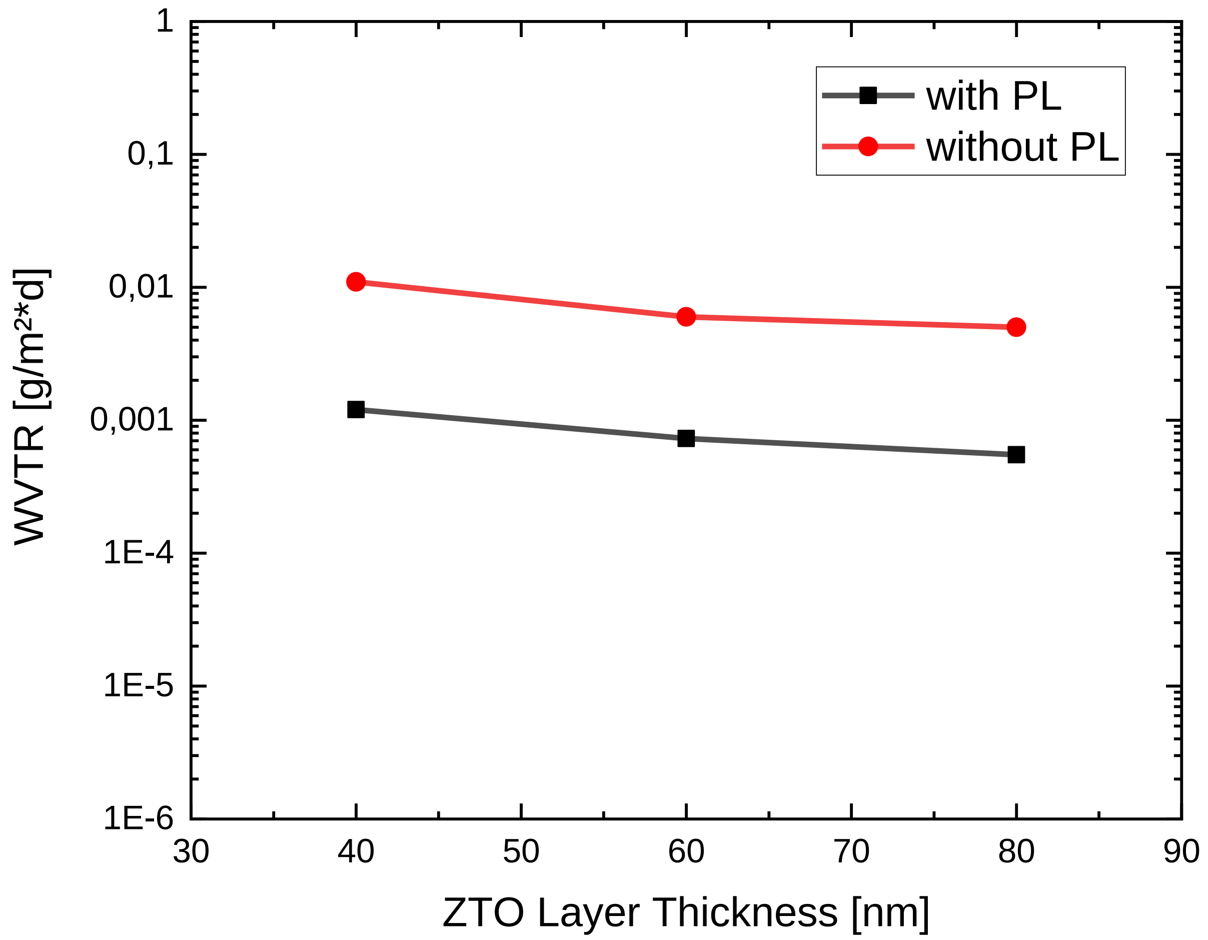
Protective films



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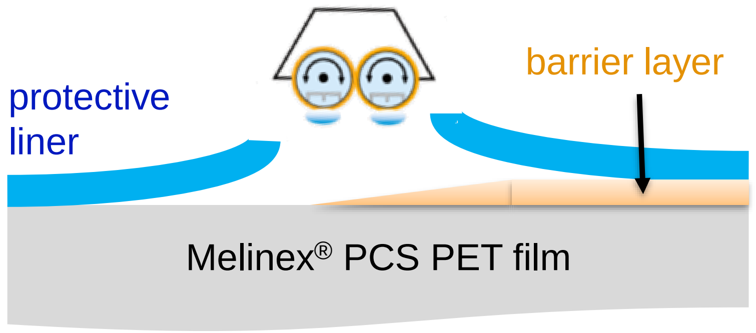

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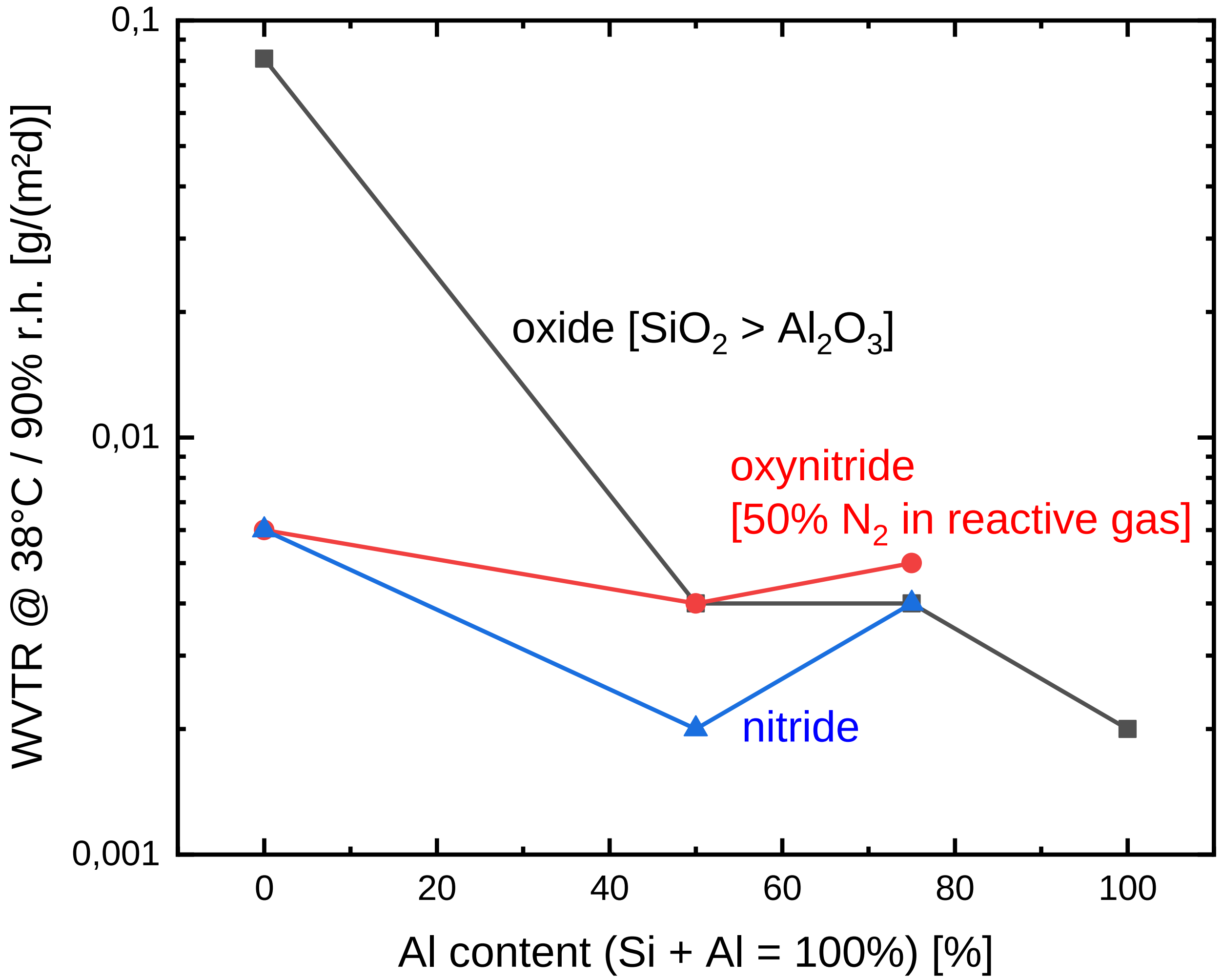
Oxide barriers – Overview

- ZTO barrier layer deposition on 3 different PCS UH modifications (reference)
- Deposition of different $SiAlO_xN_y$ modifications on Reference PCS and PCS UH modifications
  - Oxygen – Nitrogen Process Gases:
    100% O_2 ➔ 50% - 50% ➔ 100% N_2
  - Silicium – Aluminium:
    100% Si ➔ 50%/50% ➔ 75% Al ➔ 100% Al
- Evaluation of:
  - Optical Transmission / Reflection / Absorption
  - Adhesion to chosen liner Film
  - WVTR (at 38 °C / 90 % r.h. + 85 °C / 85 % r.h.)

Oxide barriers – ZTO reference

Sample	PCS-substrate	WVTR in g/(m²·d)		
Condition		38 °C, 90 % RH	60 °C, 90 % RH	85 °C, 85 % RH
ZTO 65 nm	Reference: PCS UV	$6{,}8 \cdot 10^{-4}$	$4{,}8 \cdot 10^{-3}$	$1{,}5 \cdot 10^{-2}$
	PCS-UH modification 1	$7{,}9 \cdot 10^{-4}$	$5{,}2 \cdot 10^{-3}$	$2{,}3 \cdot 10^{-2}$
	PCS-UH modification 2	$1{,}5 \cdot 10^{-3}$	$7{,}9 \cdot 10^{-3}$	$3{,}2 \cdot 10^{-2}$
	PCS-UH modification 3	$1{,}1 \cdot 10^{-3}$	$5{,}8 \cdot 10^{-3}$	$2{,}3 \cdot 10^{-2}$

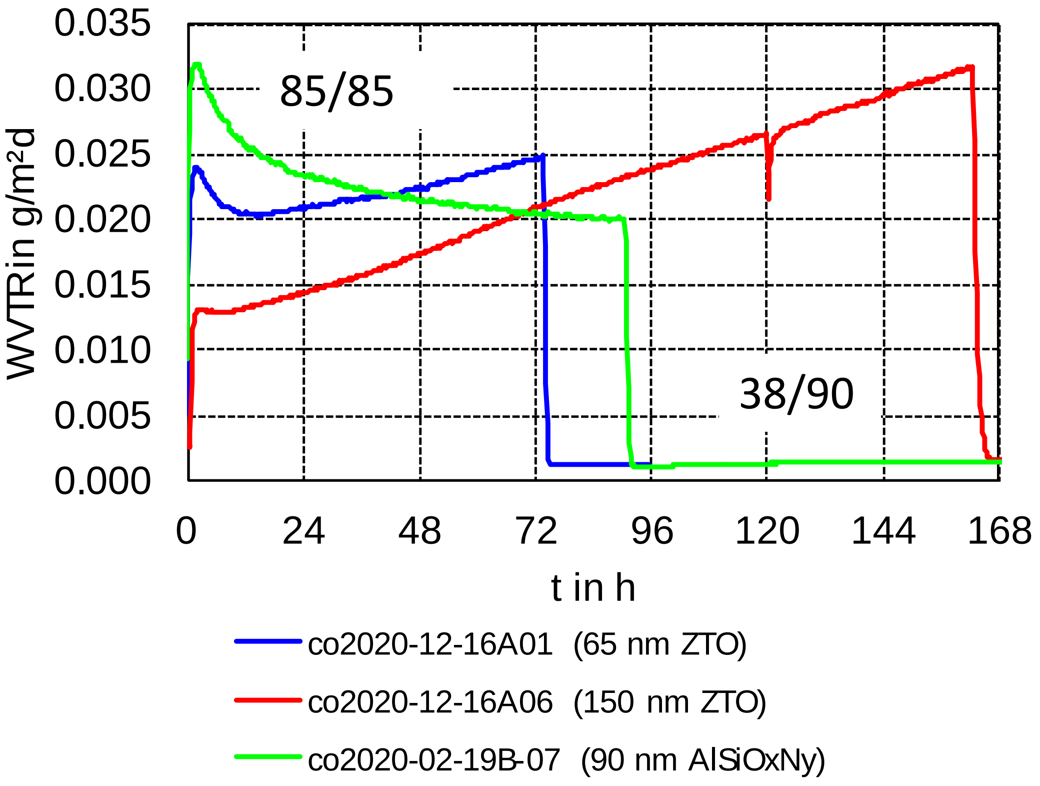
Oxide barriers – $SiAlO_xN_y$ modifications – first results



- SiO_2 and SiO_xN_y:
  WVTR > 10^{-3} g/(m²d)
  ➔ out of specifications
- all nitrides (Si_3N_4; AlN; $Si_{25\%}Al_{75\%}N_x$):
  visual light absorbance > 1%; up to 3.5%
  ➔ reduce the solar cell efficiency
- Al_2O_3 **and** $Si_{25\%}Al_{75\%}O_xN_y$:
  WVTR ≈ (10^{-3} g/(m²d) at 38°C / 90% r.h.;
  visual light absorbance < 1%

WVTR at 85 °C / 85 % r.h.

- Increasing over time for combination ZTO / liner film ➔ chemical interaction ?
- Higher Acceleration Factor for ZTO / liner film combination between 38°C and 85°C
- Constant WVTR @ 85 °C / 85% r.h. for $AlSiO_xN_y$



coating (on PCS UV or UH)	WVTR in g/(m²·d)			$WVTR_{85}$ / $WVTR_{38}$	Increase over time
-	38 °C, 90 % RH	85 °C, 85 % RH	38 / 90 after 85		85°C/85%
Water vapor partial pressure	59,7 hPa	491,4	59,7	8,2	--
65 nm ZTO	$7{,}9 \cdot 10^{-4}$	$2{,}3 \cdot 10^{-2}$	$1{,}3 \cdot 10^{-3}$	29,1	Yes
150 nm ZTO	$3{,}6 \cdot 10^{-4}$	$3{,}0 \cdot 10^{-2}$	$1{,}3 \cdot 10^{-3}$	83,3	Yes
90 nm $AlSiO_xN_y$ (on PCS-UV)	$2{,}8 \cdot 10^{-3}$	$2{,}0 \cdot 10^{-2}$	$1{,}4 \cdot 10^{-3}$	7,2	No

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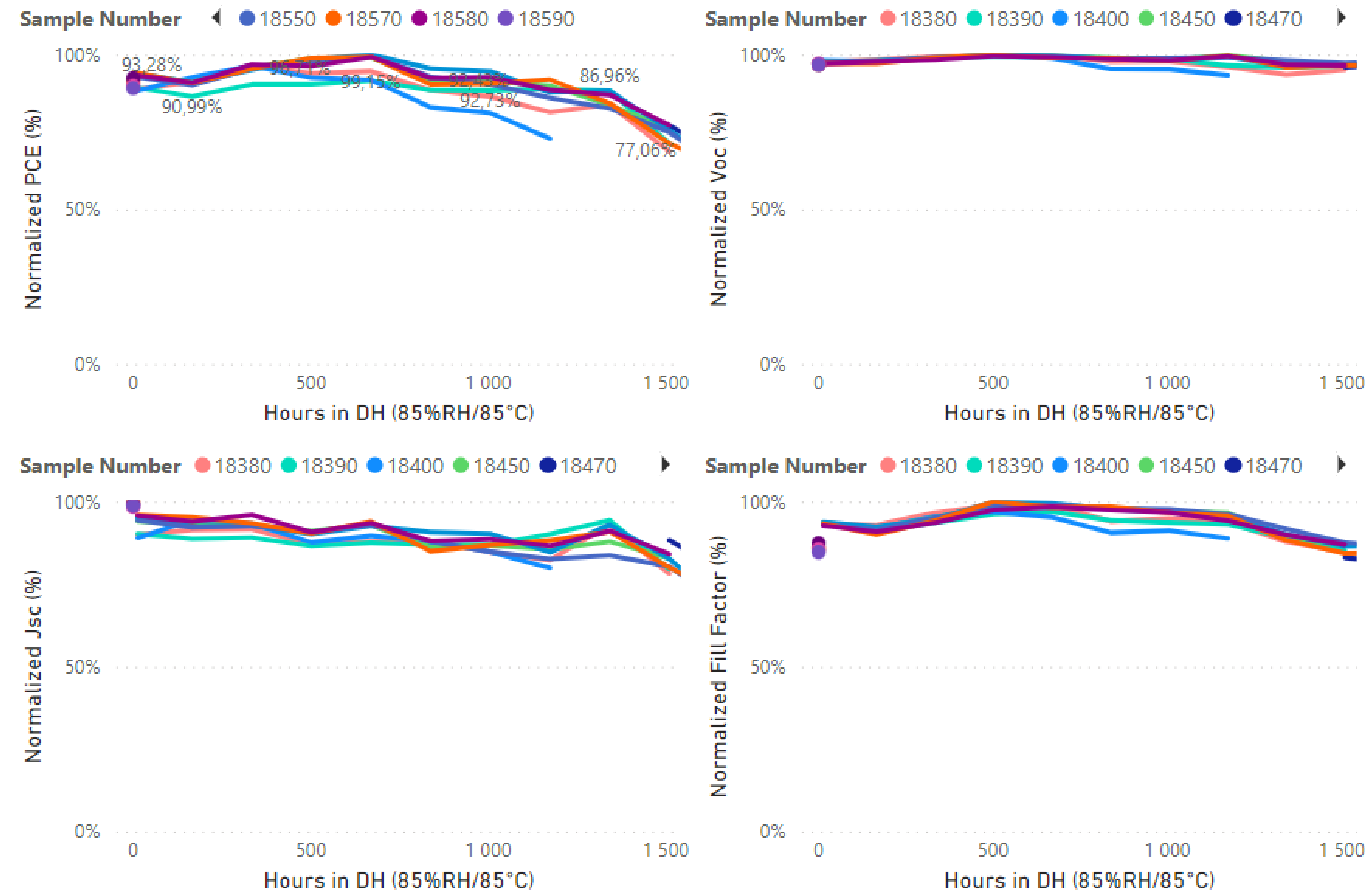
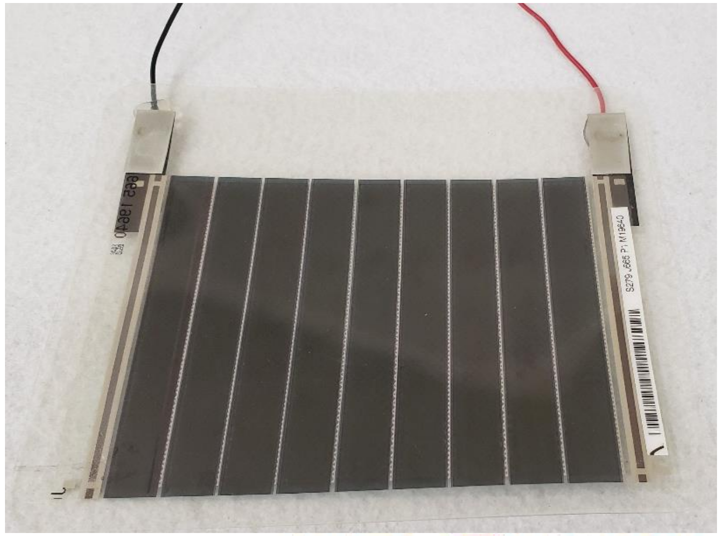
OPV Cell performance

Oxide barriers – OPV cell performance with Al_2O_3 barrier



- Very Stable
- T80 still not reached after more than 1000h of DHT 85 °C and 85 % r.h. for all the samples



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Conclusion and Outlook

- **Substrate Material**
  - PCS UH is UV and hydrolysis stabilized
  - Light scattering surface with particles can damage the barrier
  - Structured hard coat will be tested soon
- **Barrier Material**
  - Liner Film protect barrier coating
  - ZTO reference meets requirements on new substrate material
  - Some $AlSiO_xN_y$ combinations are suitable regard to barrier performance and optical properties
- **Cell Performance**
  - Sample of Al_2O_3 very stable after 1000 h DHT 85 °C / 85 % r.h.

THANK YOU FOR LISTENING

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European Union

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