The **future**
belongs to those
who **create** it

Holst Centre

Open Innovation by imec and TNO

R2R pilot line production of high performance moisture barriers

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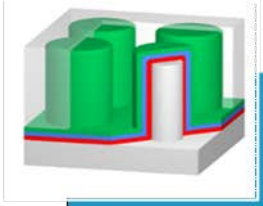
Research areas in Holst Centre

Energy devices

OLED Lighting

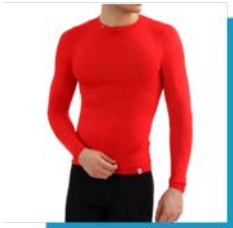
Flexible PV



Solid state batteries

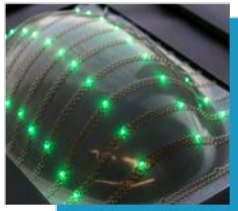
Smart windows

Integrated Electronics



Wearables

Health patch



Conformable PCB

TFT devices & Logic

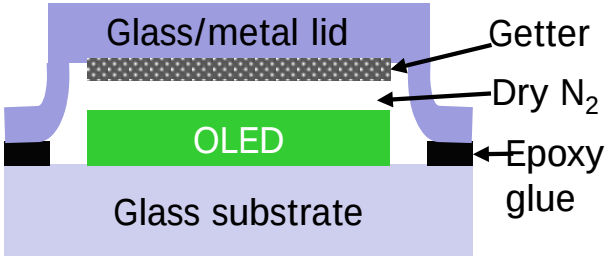
Flexible displays

Flexible X-ray

Flexible circuits

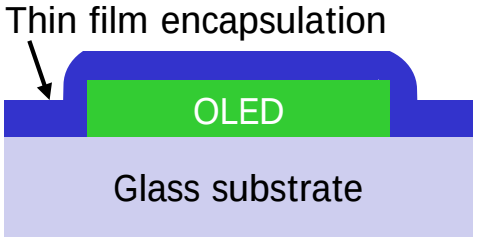
OLED Encapsulation/Barrier

(a) Current standard:
Glass OLED with metal/glass lid and getter

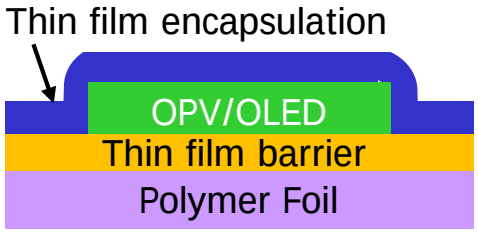


(+) Lifetime
(-) Expensive
(-) Difficult to scale up
(-) Not flexible

(b) Glass OLED with Thin Film Encapsulation



(c) ***Flexible* OLED** on foil with Barrier on both sides

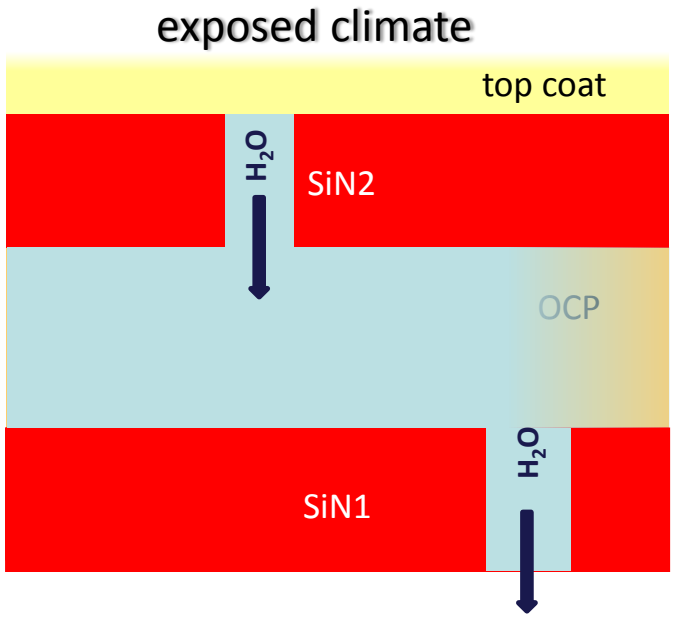


Cost

Time, Manufacturing Scalability, Mechanical Flexibility

Thin film barrier concept Holst Centre

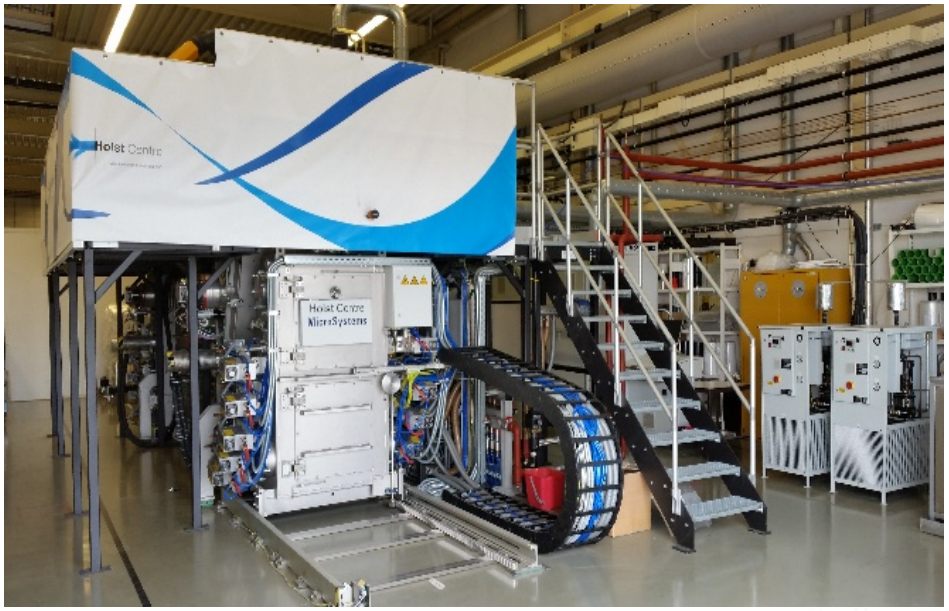
S2S and R2R barrier (direct/indirect encapsulation)



- **2 SiN layers with an organic layer in between**
- **The organic layer (OCP) is several microns thick: all pinholes in both SiN layers are de-coupled.**
- **Further improvement by including nano getter particles in the organic layer (CaO or nano zeolite particles)**

OCP= organic coating for planarization

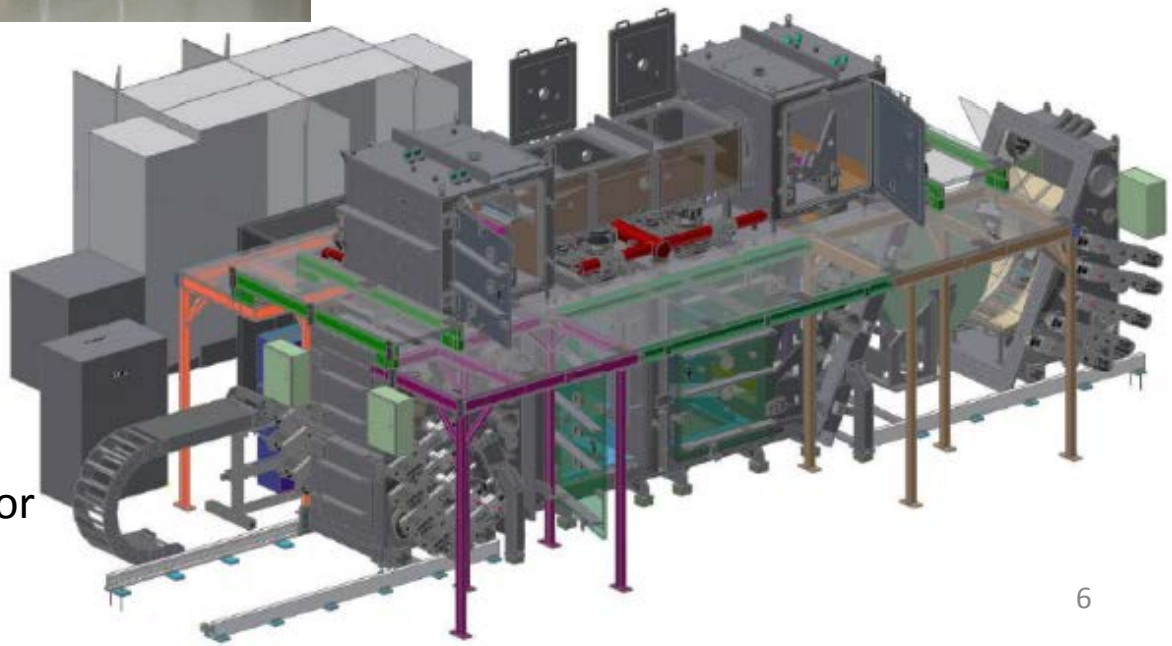
R2R barrier film pilot line (Rollcoat)



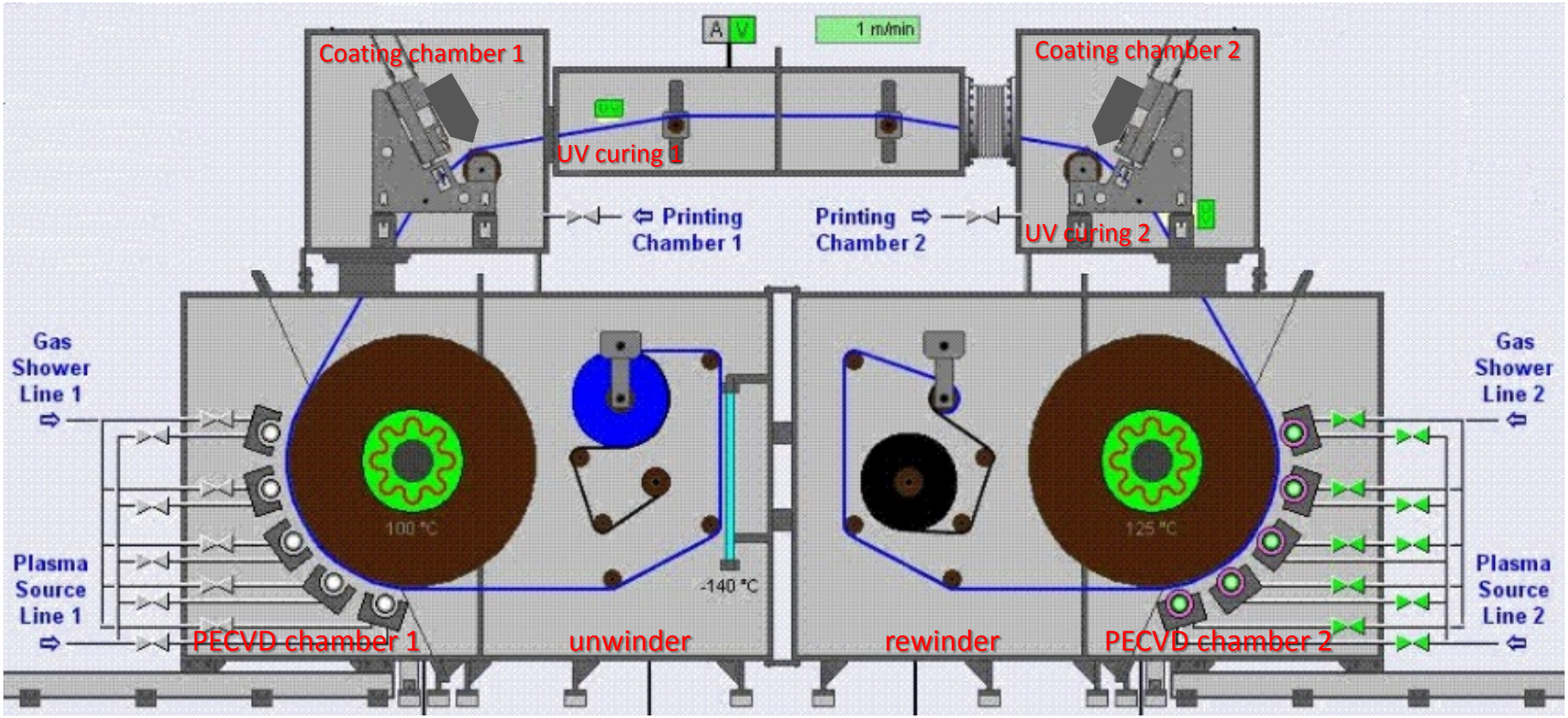
R2R barrier ambition:

Develop a thin, transparent, flexible an low cost barrier on foils that can be used for OPV and OLED applications

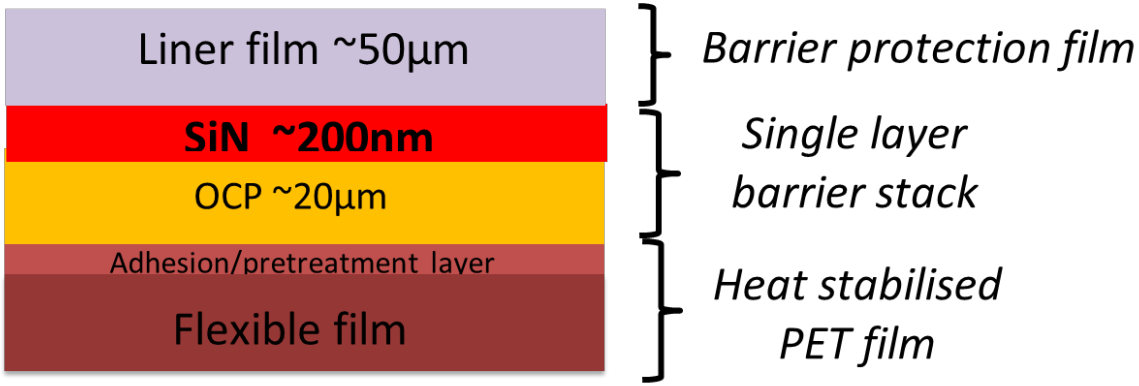
- R2R PECVD high rate low temperature deposition
- Slot die coating of planarization, getter and topcoat coatings
- Webhandling system suited for 500mtr foil (width 400mm)



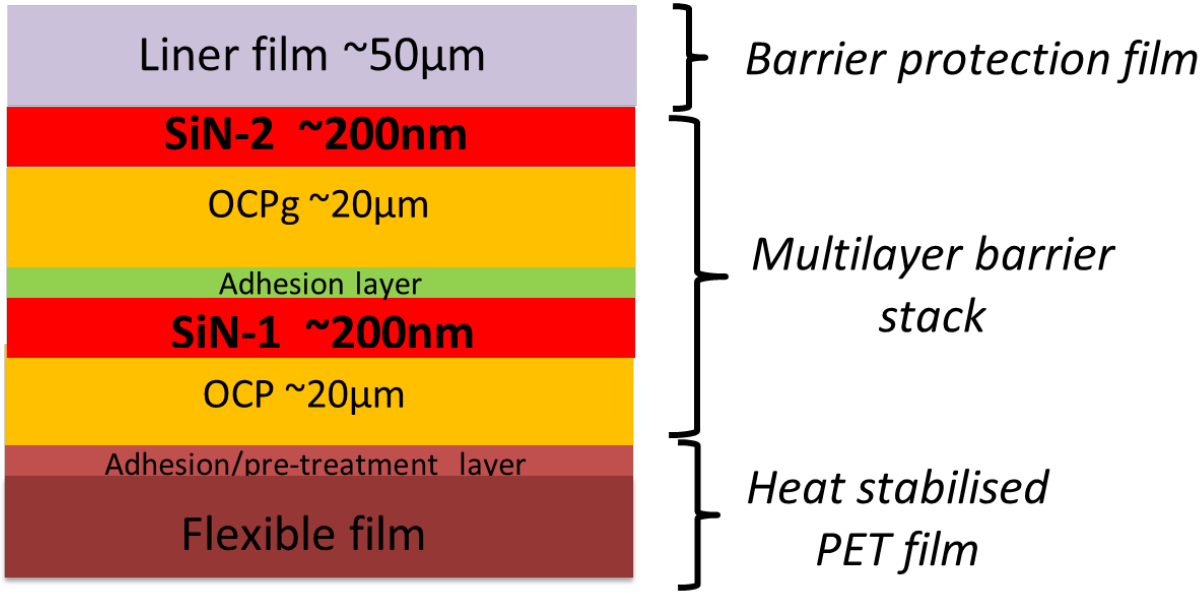
R2R barrier deposition (Rollcoat)



Single/Multilayer barrier stack



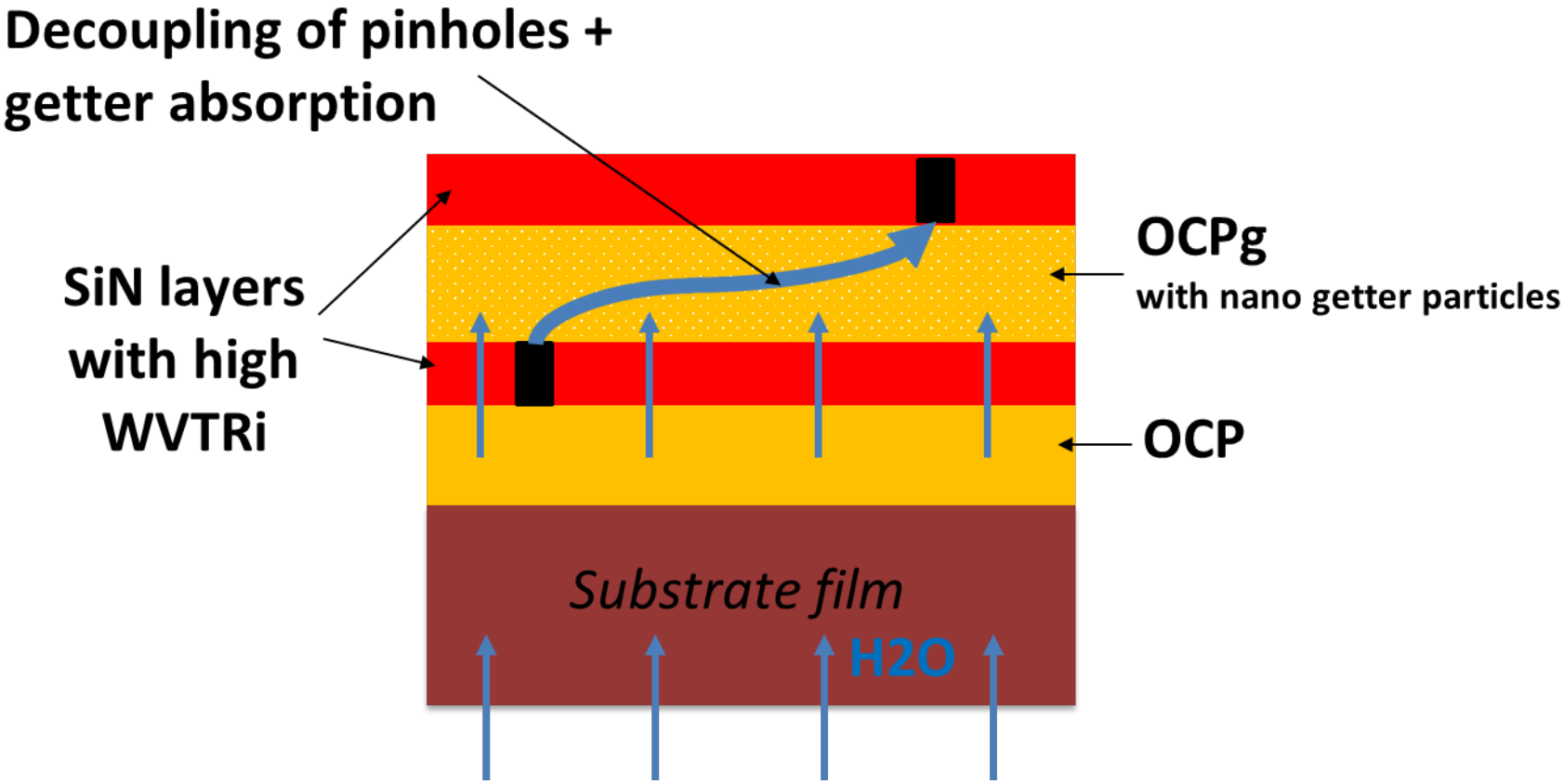
1 dyad barrier used for OPV applications



2 dyad barrier used for OLED lighting and display applications

OCP= organic coating for planarization
OCPg=org. coating for plan. with getter

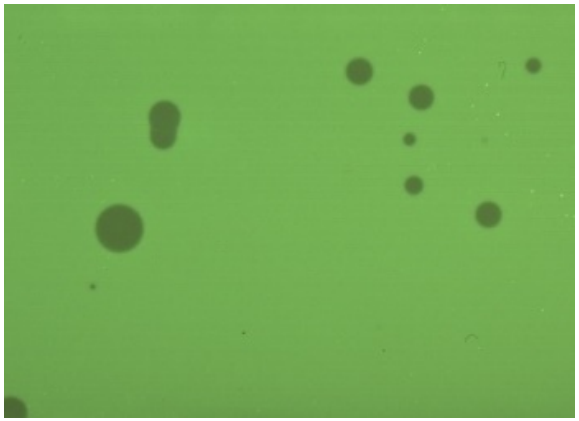
2 Dyad multilayer barrier with special organic coating with getter particles (CaO or Nanozeolite)



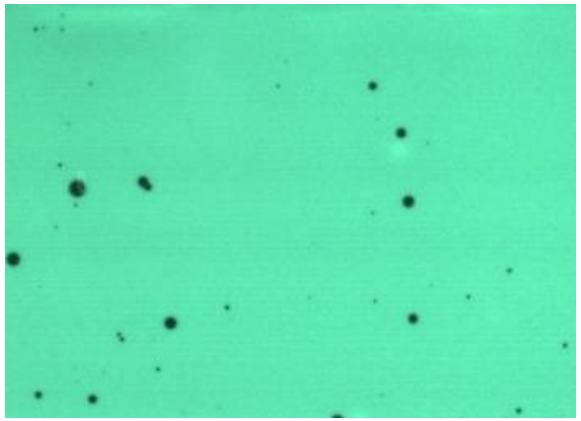
OCPg (5% CaO) optimization for OLED on foil

PEN-OCP-SiN_1-OCP_g-SiN_2- **OLED** -SiN_3-OCP_g-SiN_4-OCP

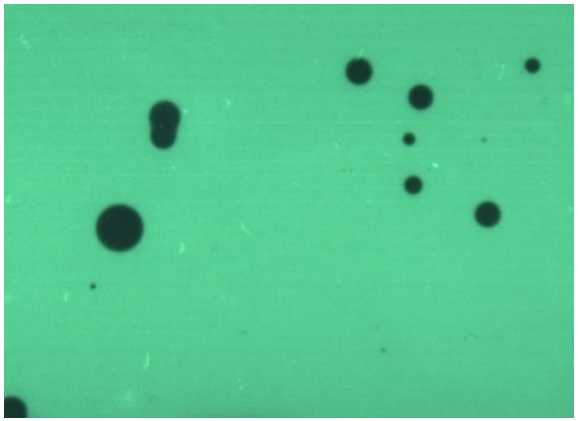
emission



top barrier



bottom barrier



- Scattering of CaO getter in bottom barrier improves efficacy by 30%
- Improved efficacy is lost when getter is saturated: spots of reduced emission
  - Spots in top barrier are acceptable for bottom emitter (backside, Al foil)
  - Spots in EL related to spots in bottom barrier are not acceptable

WVTR: extrinsic vs intrinsic degradation

Water Vapour Transmission Rate – units: g / m² / day

The total amount of water going through a film per unit area, per unit time

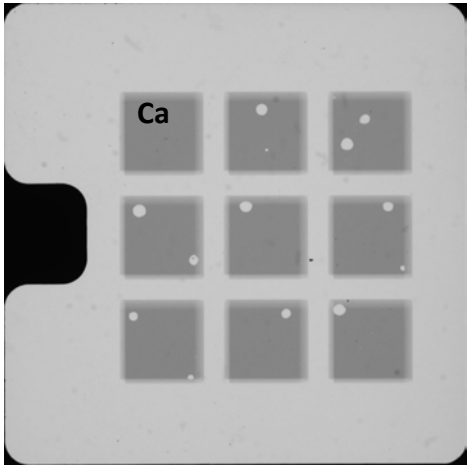
For a single barrier layer (total/overall) WVTR dependent on:

- porosity of the material
- thickness of the layer

} **Intrinsic WVTR**

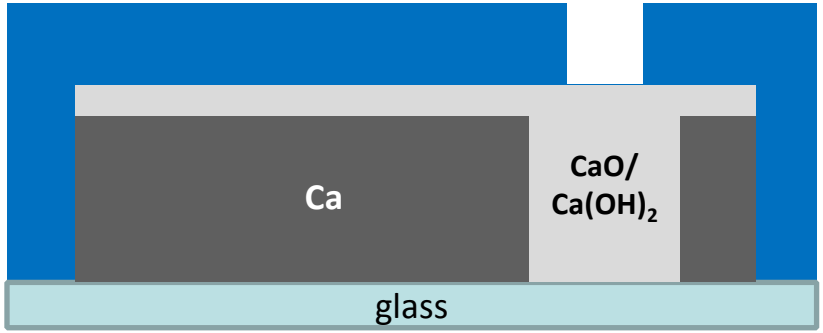
- number of pinholes in the layer:

} **Extrinsic WVTR**

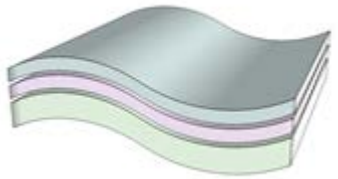


Extrinsic WVTR
(for good barrier layers: dominant)

Caused by:
- particles
- Roughness substrate
- External damage



Measured R2R single layer barrier quality

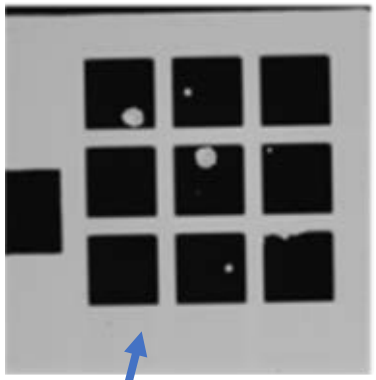


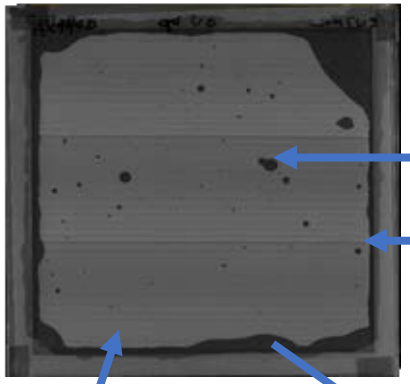
- **Mocon Aquatran-1 test at 38°C/90%RH**
  WVTR < 5.10-4 g/m2.day @38°C/90%RH, this is below the detection limit.

- **Ca test at 60°C/90%RH**
  WVTRi < 5.10^{-6} g/m2.day @20°C/50%RH with low pinhole density 0.05-0.5ph/cm2

- **Pinhole/WVTRe test at 85°C/85%RH**
  WVTRe < 1.10^{-6} g/m2.day @20°C/50%RH
  pinhole density 0.05-0.5ph/cm2

R2R WVTRe and pinhole measurements

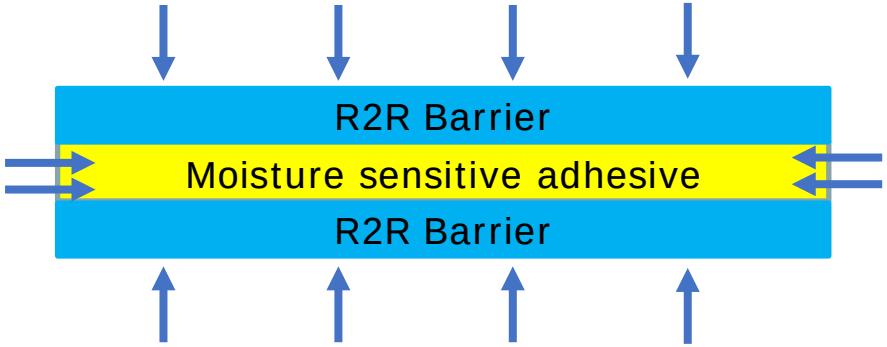




Pixeldefects

Side leakage

Ca test @60°C/90%RH :
WVTRi <5.10-^{6} g/m2.day
@20°C/50%RH

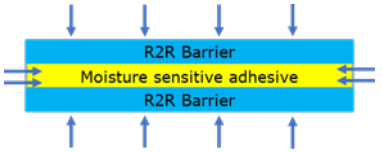


WVTRi/pinhole test@85°C/85%RH :
Two barrier films are laminated together with in between an IJ-printed moisture sensitive adhesive

The UV curable moisture sensitive adhesive is a non transparant milky coating, it contains 5% CaO. By water ingress the CaO is converted to $Ca(OH)_2$ and the layer/pinholes get transparant and visible.

R2R multilayer barrier pinhole tests

(with nanozeolite getter/ no extra adhesion layer)



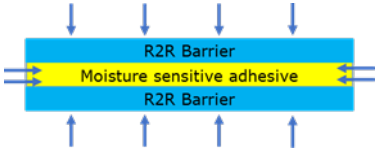
Single barrier

Multilayer super high-end barrier

~0 saturation spots in 20 years
(test still running)

R2R multilayer barrier pinhole tests

(with nanozeolite getter and extra adhesion layer)



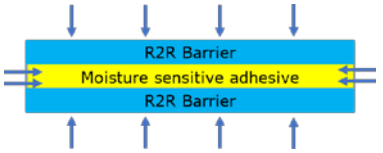
Single barrier

Multilayer super high-end barrier

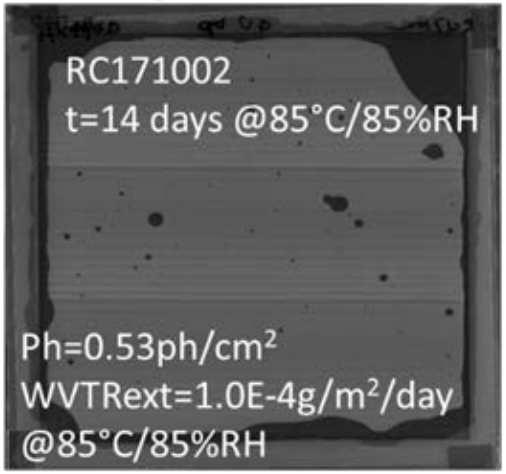
~0 saturation spots in 5 years
(test still running)

R2R multilayer barrier pinhole tests

(with nano CaO getter and extra adhesion layer)



Single barrier



Multilayer super high-end barrier

~0 saturation spots in 11 years
(test still running)

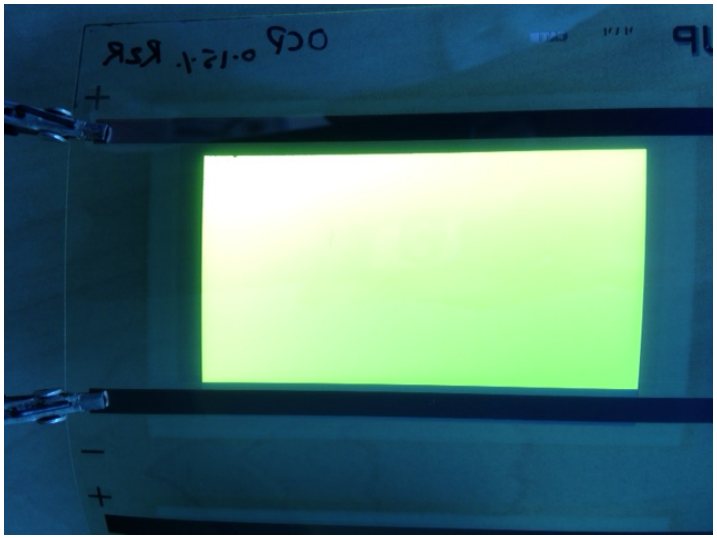
R2R multilayer barrier on OLED devices

*PET-OCP-SiN_1-$OCP_{(0.15\%\ CaO/NZ)}$-SiN_2 – **OLED** - SiN_3-$OCP_{(0.15\%\ CaO)}$-SiN_4-$OCP_{(0.15\%\ CaO)}$*

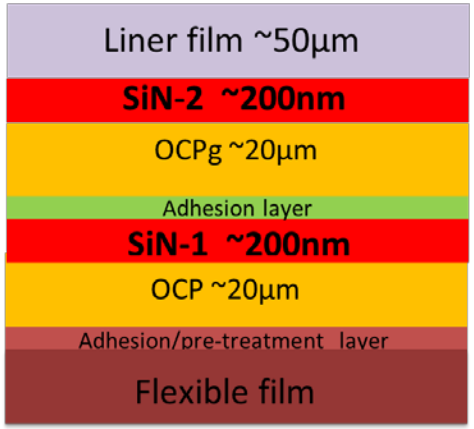
Black spot analysis on flexible **smOLEDs** with full R2R spotless bottom barrier (and standard TFE top barrier) just started to compare performance of 0.15% CaO and nano-zeolite.

Nanozeolite vs CaO 0.15%:

- better adhesion
- longer lifetimes (indicated by side leakage experiments)
- but….only physical getter

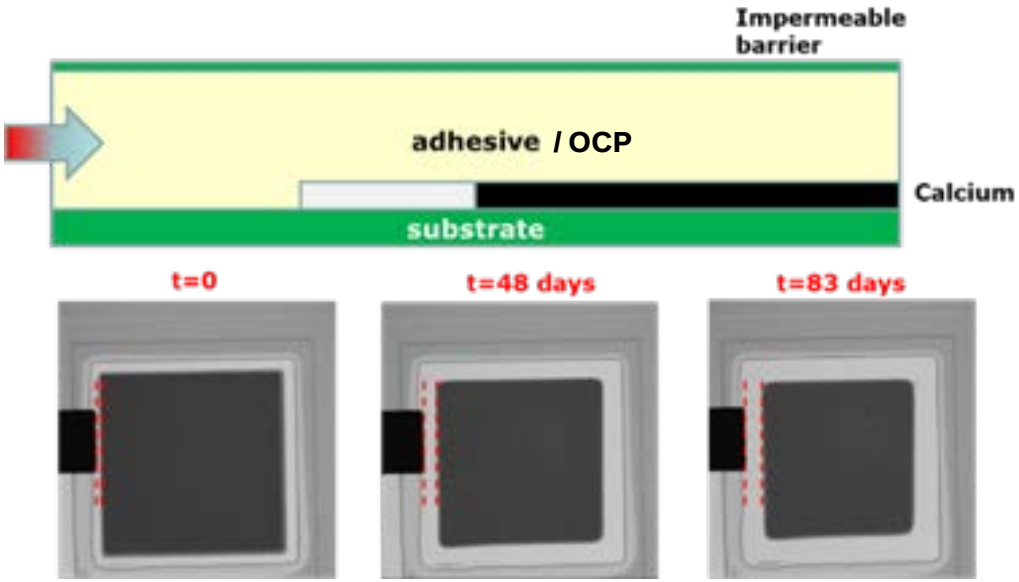


R2S smOLED 25x45mm emission area



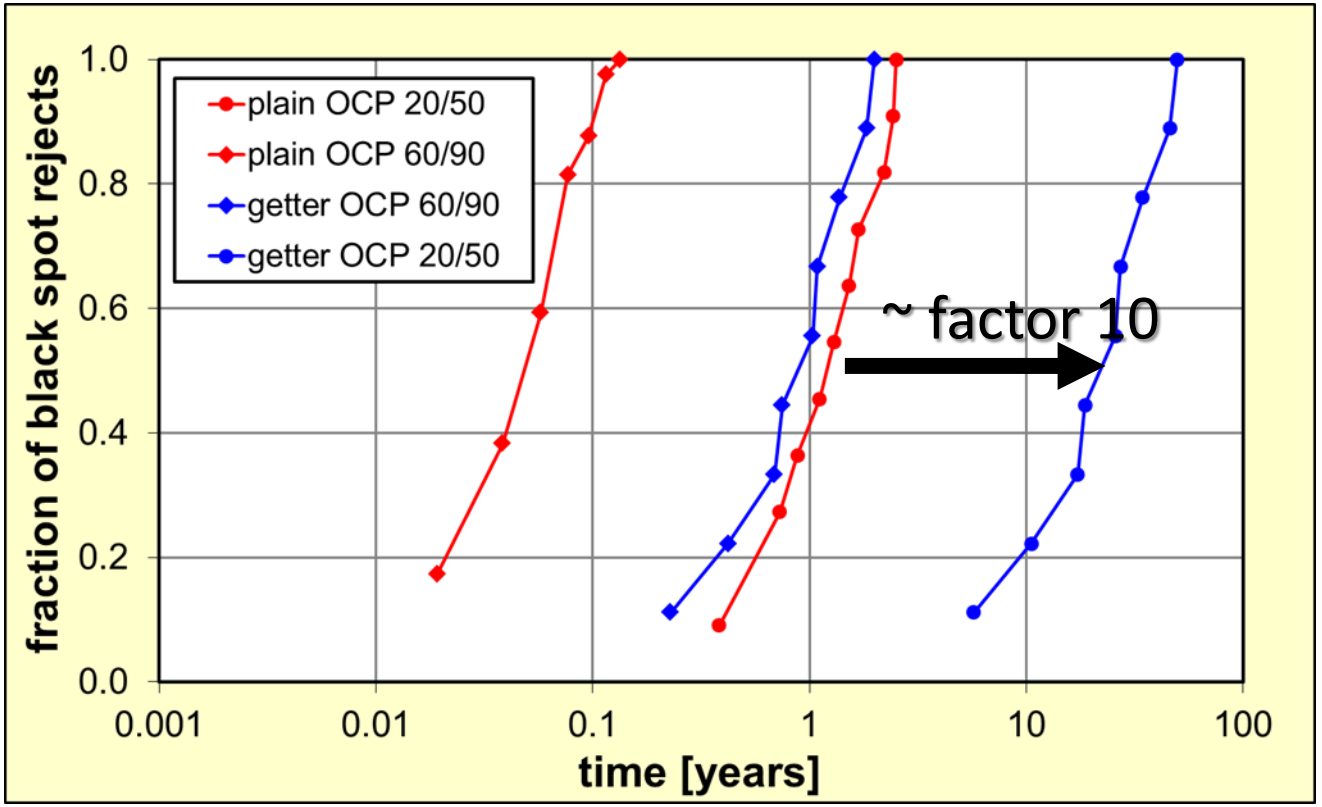
Used R2R multilayer barrier film

Side leakage measurements S2S



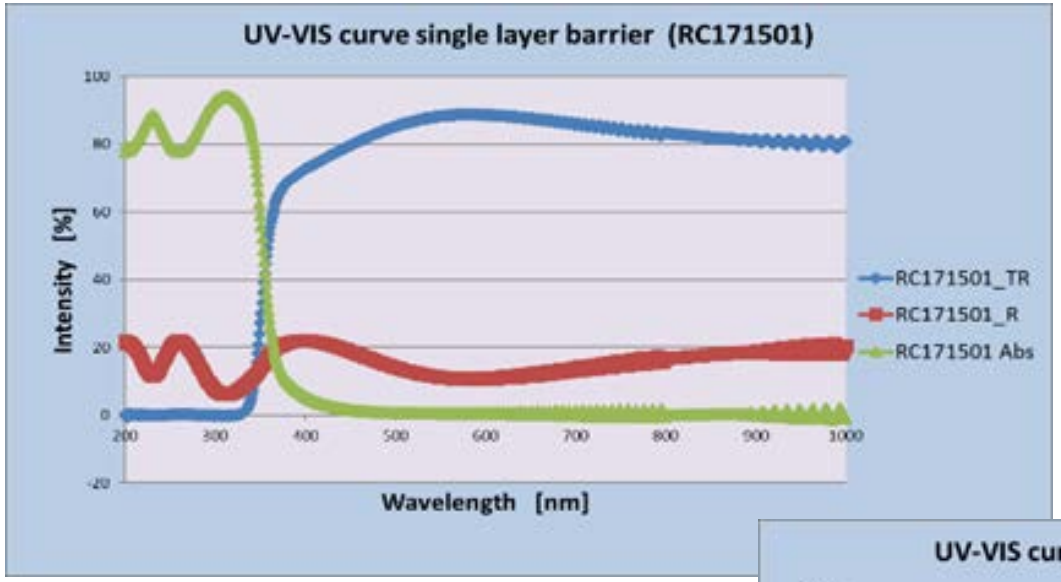
material	side leakage [mm/hrs$^{0.5}$]	spot growth	
		[mm^2/hrs]	rel to 5% CaO
plain OCP	0.75	0.56	10.6
OCP 0.15% CaO	0.60	0.36	6.8
OCP 5% CaO	0.23	0.05	1.0
nano-zeolite	0.40	0.16	3.0

Fraction of black spot rejects in S2S OLED device for plain OCP and getter OCP



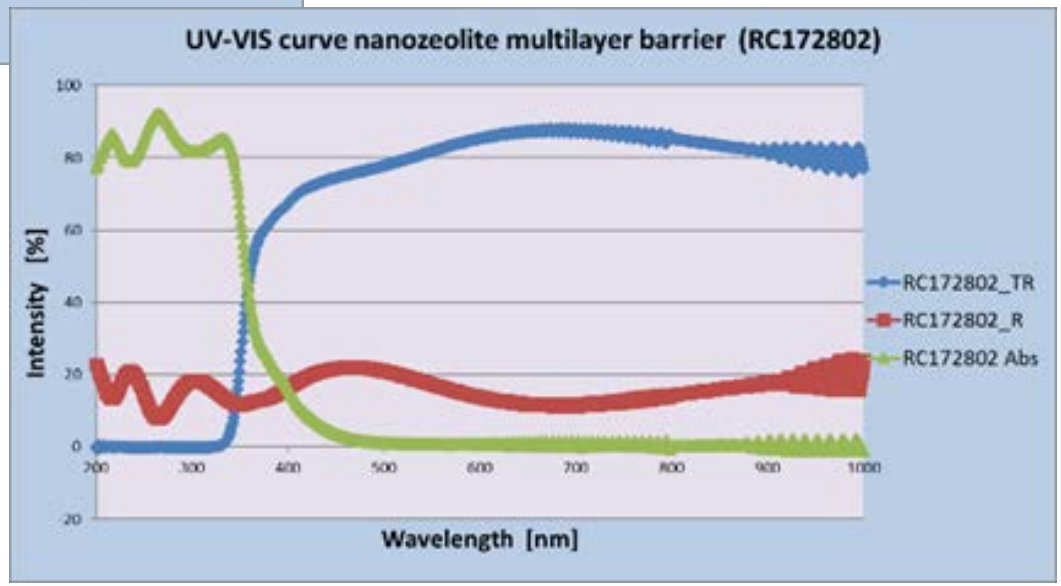
Glass-OLED-SiN-OCP-SiN-OCP (Org. Electr. **44** 94-98 (2017))

Optical quality transparent 2R barrier film



Transparant barrier film:

No light absorption in the visible spectrum (400-800nm) for single layer as multilayer barrier film

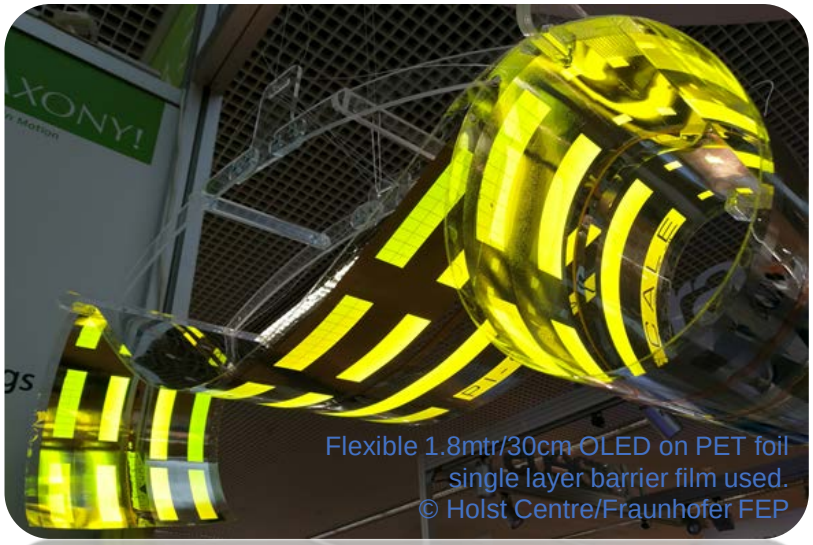


R2R barrier pilot line summary

- The R2R barrier pilot line is capable for barrier production of 500mtr foil reels. Single barrier layer quality with WVTR <5.10^{-6} g/m^2.day and low pinhole amount 0.05-0.5 ph/cm^2
  - The R2R single barrier film (OCP-SiNx stack) is perfectly suited for flexible OPV solutions

- The new developed R2R multilayer barrier (OCP-SiN1-OCPg -SiN2) is suited for OLED applications. WVTR tests show lifetimes of > 10 years with a pinhole amount of 0 ph/cm^2

- Start of a new open access flexible OLED pilot line
  (European project PI-Scale)



Flexible 1.8mtr/30cm OLED on PET foil
single layer barrier film used.
© Holst Centre/Fraunhofer FEP

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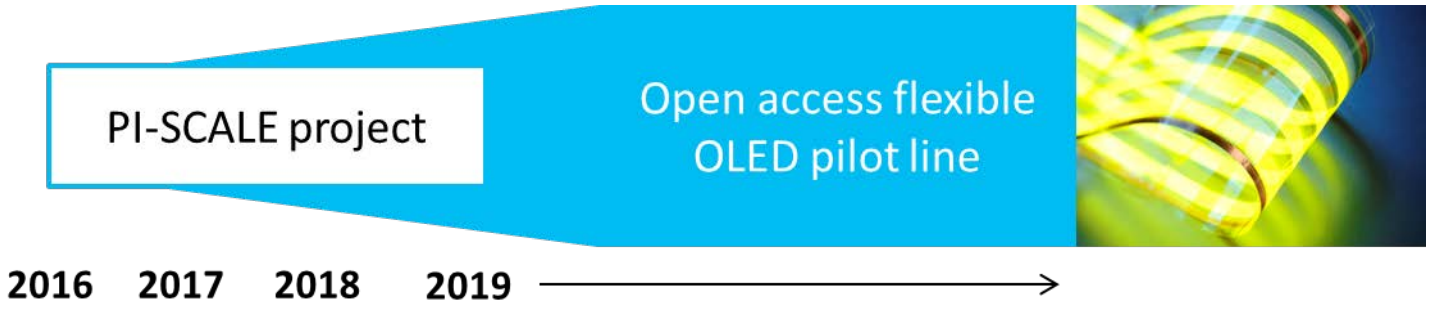
PI-Scale



Vision

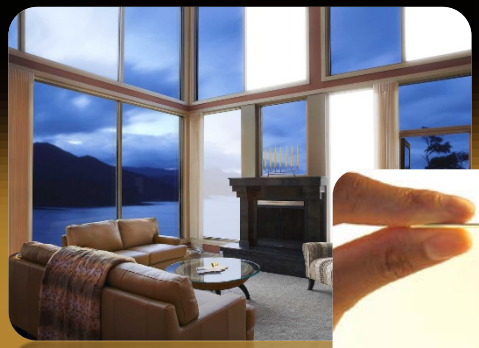
- Light that is beautiful to look at by making **customized** flexible OLEDs in any shape, color, design, and reflective or transparent
- Support the creation of a **sustainable industry** around flexible OLEDs in **Europe**

Mission

- Our pilot line offers the **latest innovations** on flexible OLEDs that are unique in the world and it allows our customers to develop first-of-a-kind **innovative products** with flexible OLED
- With the pilot line and our flexible OLED knowledge, we bridge the gap between R&D and mass manufacturing both on **features** and on **quantities**

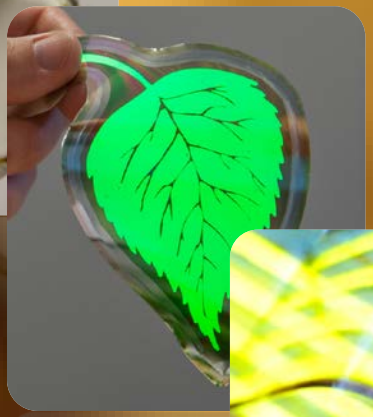
Flexible OLED Features

No glare, area lighting



Flexible

Ultra thin



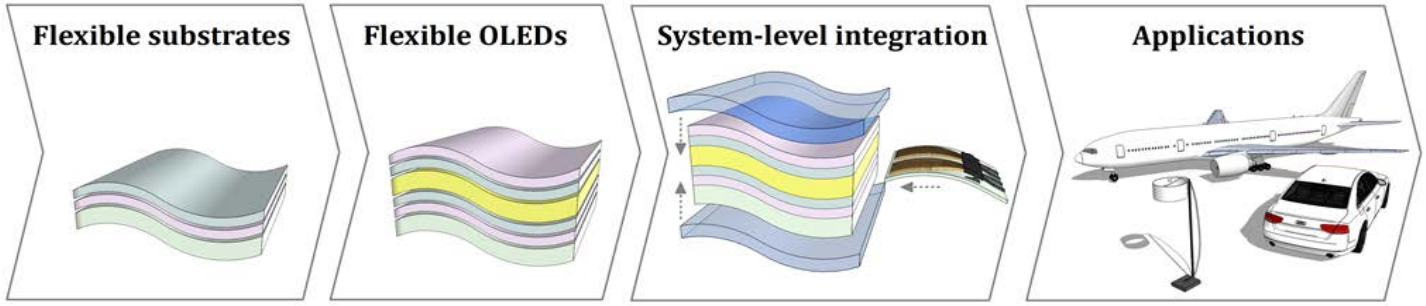
Transparent

Any shape & colour

Large form factor

Enable new applications

PI-Scale consortium



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Open Innovation by imec and TNO

Fraunhofer FEP

REHAU

Brabant Development Agency
BOM

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development of light

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