GPD Finland 2017 Workshop
"Advances in Coatings for Glass and Plastics"
June28,2017, Tampere

"Flexible organic electronics & R2R coating technologies in Fraunhofer FEP"

Koichi Suzuki
*President of SurFtech Tranantional Co.,Ltd.
*Japanese Representative of Fraunhofer FEP
*Secretary of ICCG
E-mail: koichisuzuki@surftech.co.jp

Content

1. Background

2. R2R coating technologies
   1) Key component technologies
   2) Coatings on flexible ultra thin glass

3. Flexible OLD lighting

4. Summary

Background of my activities

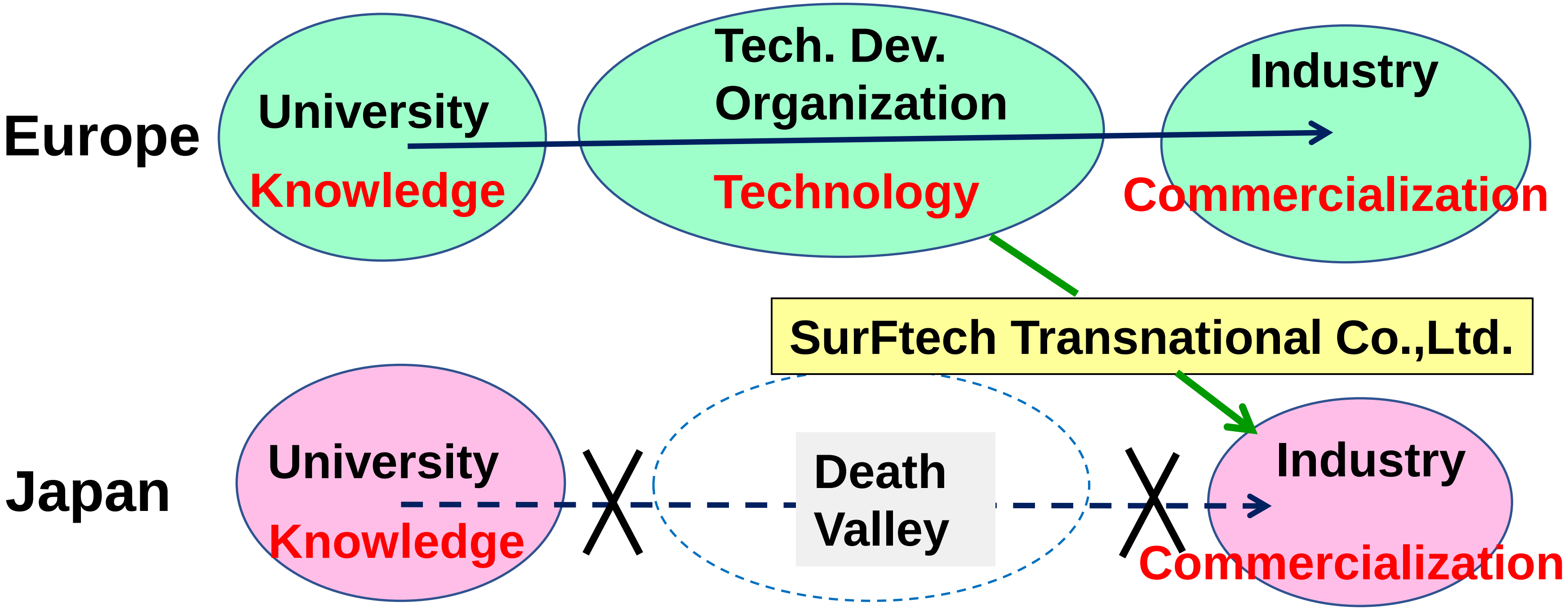
1992~1996： Technical advisor in Belgium glass company

Contacts with various European institutes through ICCG

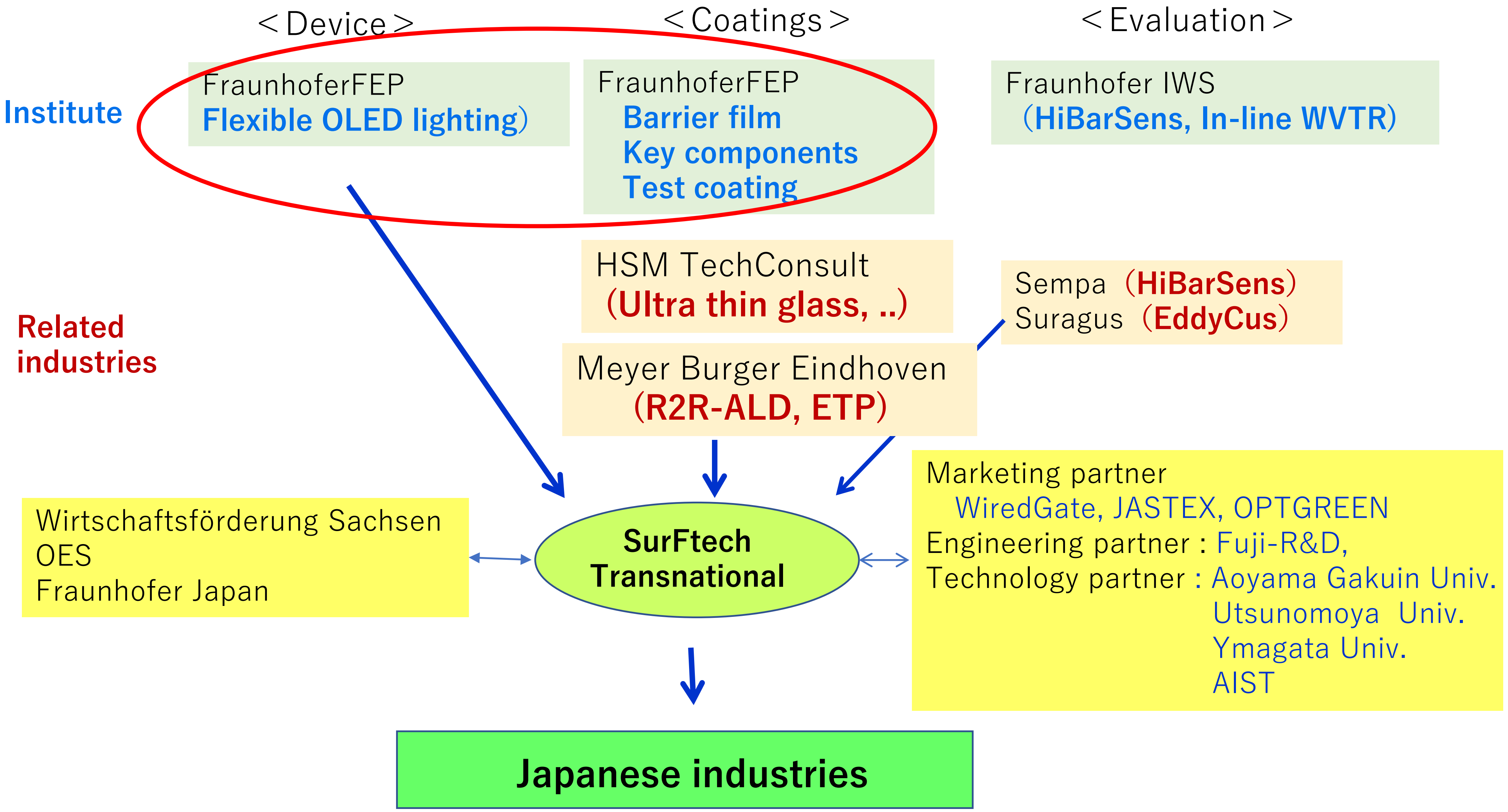
1998～Now: Technology transfer business as SurFtech Transnational Co.,Ltd

Germany: Fraunhofer, INM

The Netherlands: TNO



Coordination of EU-Japan Collaboration for Organic Electronics



Fraunhofer FEP

for Organic Electronics, electron beam, plasma technology

Foundation: 1991
Staffs： 216

＊World top level in vacuum coating
＊Development for 2 years ahead
＊**Technology package with hardware**
＊OLED

- Core competences:

ELECTRON BEAM TECHNOLOGY | SPUTTERING TECHNOLOGY | PLASMA-ACTIVATED HIGH-RATE DEPOSITION | HIGH-RATE PECVD | TECHNOLOGIES FOR ORGANIC ELECTRONICS | IC AND SYSTEM DESIGN

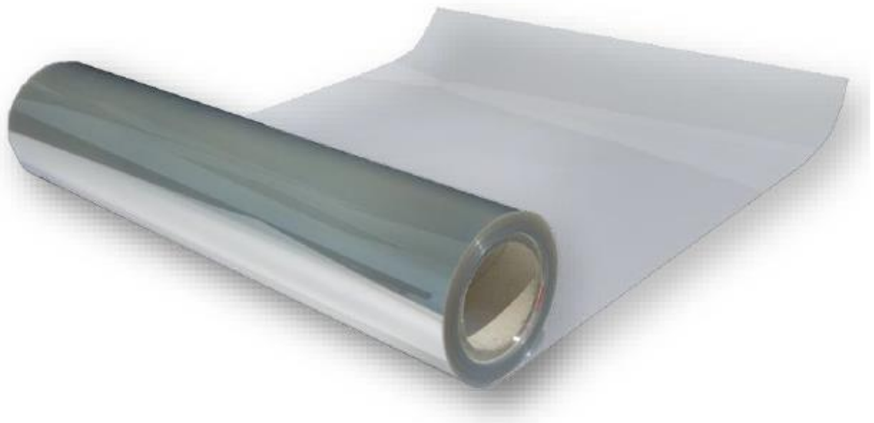
Fraunhofer FEP

SurFtechTransnational

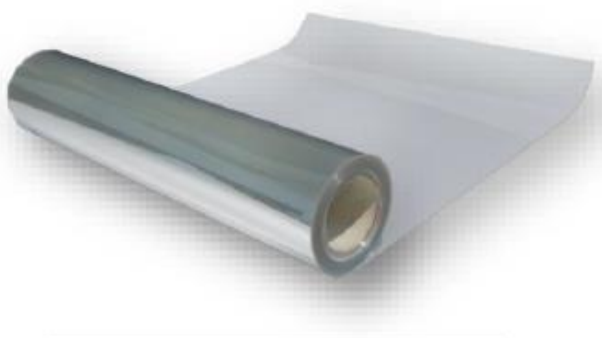
What FEP can do for various industries?

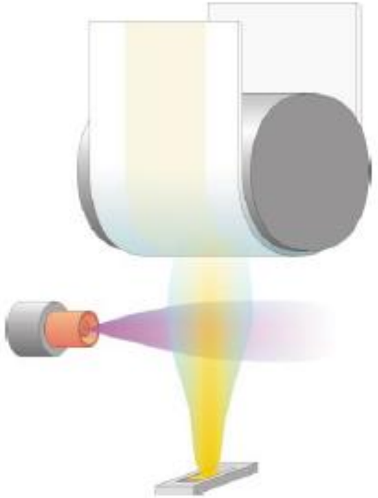
R2R coating technologies

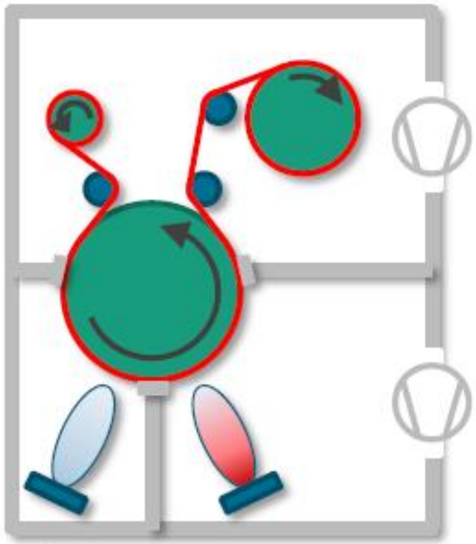
for flexible organic electronics



FEP's business field based on R2R coating technologies







testing
substrate materials

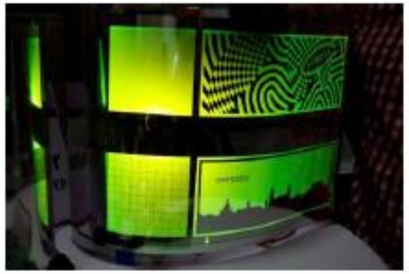
→

developing
coating technologies

→

developing
key components

→



pilot production

→

application

business field
Flexible Organic Electronics

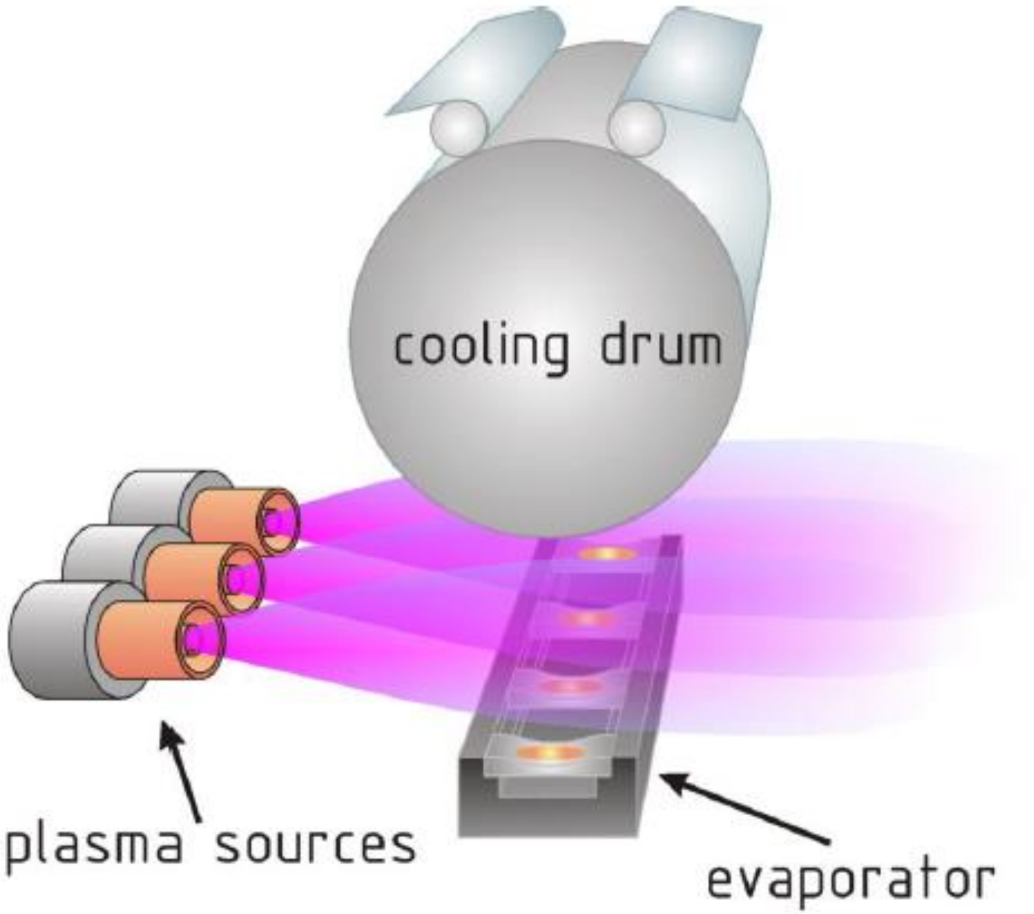
FEP's key component technologies for pilot and production

1. **H**ollow cathode discharge **A**ssisted high rate **D**eposition (**HAD**)

2. High rate PECVD (magPECVD, **arcPECVD**)

3. High rate sputtering for precision optics(**RM**) with pulsed powering & process control

1, Hollow cathode discharge Assisted high rate Deposition (HAD)



Discharge current ~ 200A/gun

Extremely high density plasma

Strong ion bombardment

Dense coating with high rate
> **2000nm.m/min**

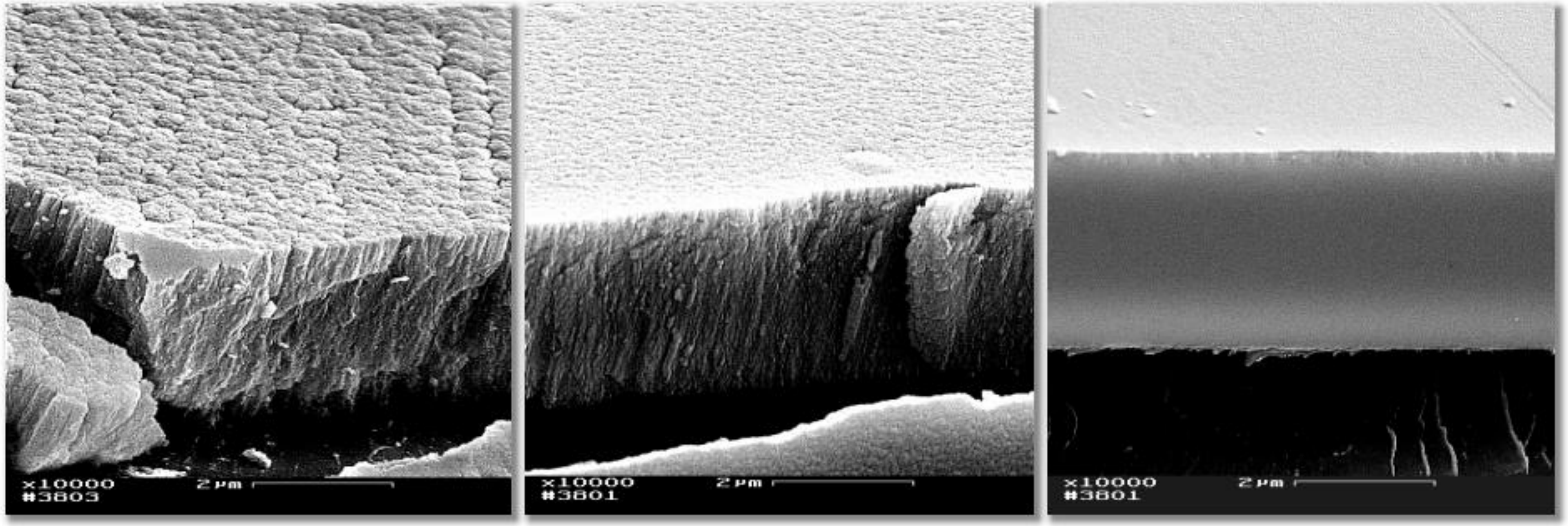
<Similar plasma gun>

***UR gun in Japan**
(Pressure gradient arc plasma gun)

***ETP source in The Netherlands**
(Cascade arc plasma gun)

Effect of Plasma Activation

Example: Al_2O_3 on PET at 100 nm/s



Al_2O_3 by reactive evaporation	Al_2O_3 by reactive evaporation	Al_2O_3 by reactive evaporation
Discharge current: **0 A**	Discharge current: **200 A**	Discharge current: **400 A**
Layer hardness: **3.2 GPa**	Layer hardness: **5.0 GPa**	Layer hardness: **6.3 GPa**

Dense amorphous layer morphology by plasma activation

Linear plasma gun for large area high rate deposition

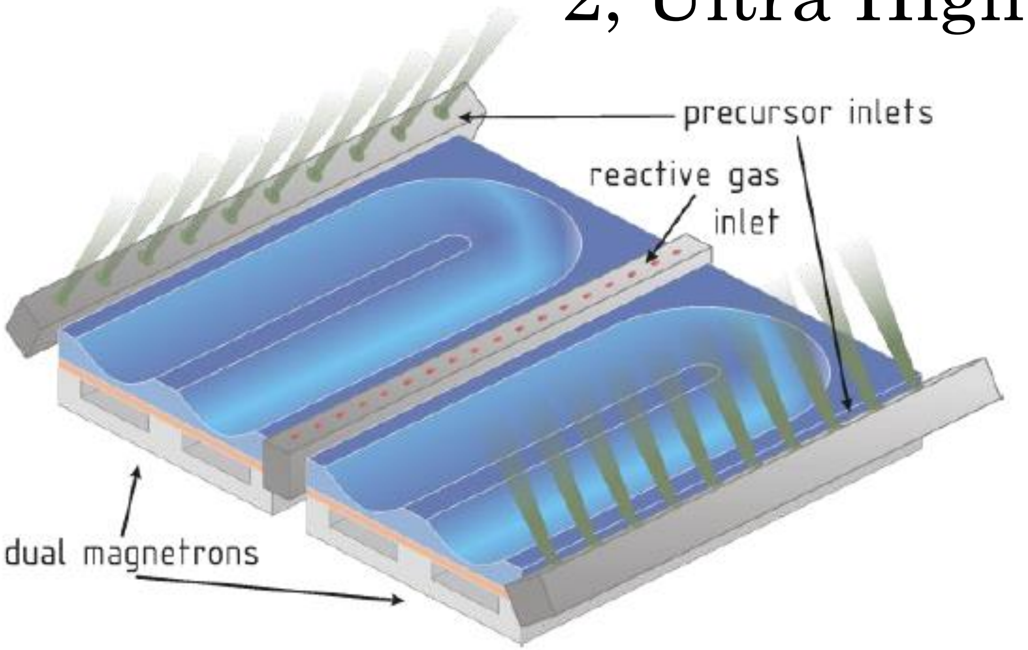
310cm

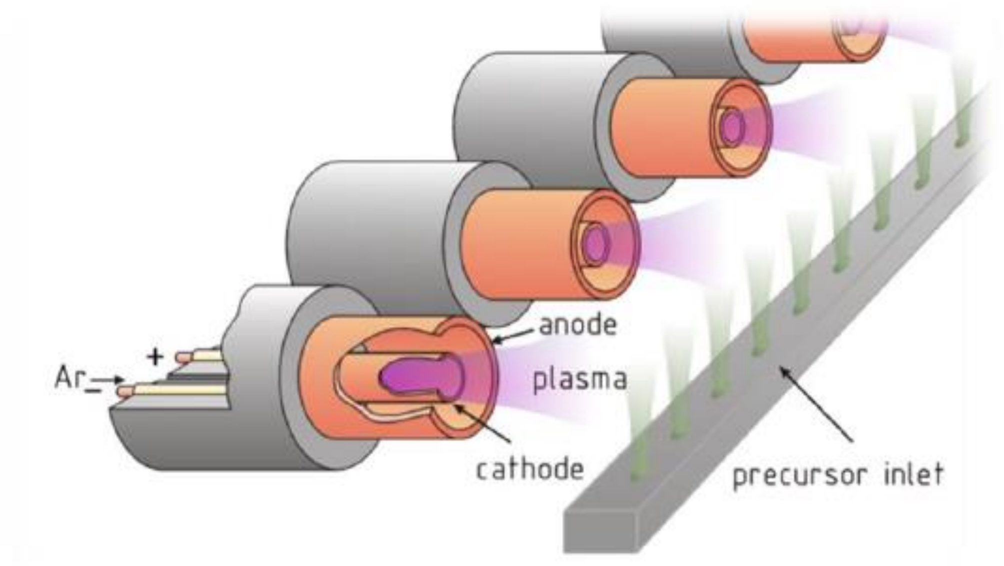
Current application
➔Food packaging
(~20nmAlOx, 9m/s)

Hardware
➔ready for production!

Application also to
➔ arcPECVD !!

2, Ultra High Rate PECVD





Dual Magnetron PECVD

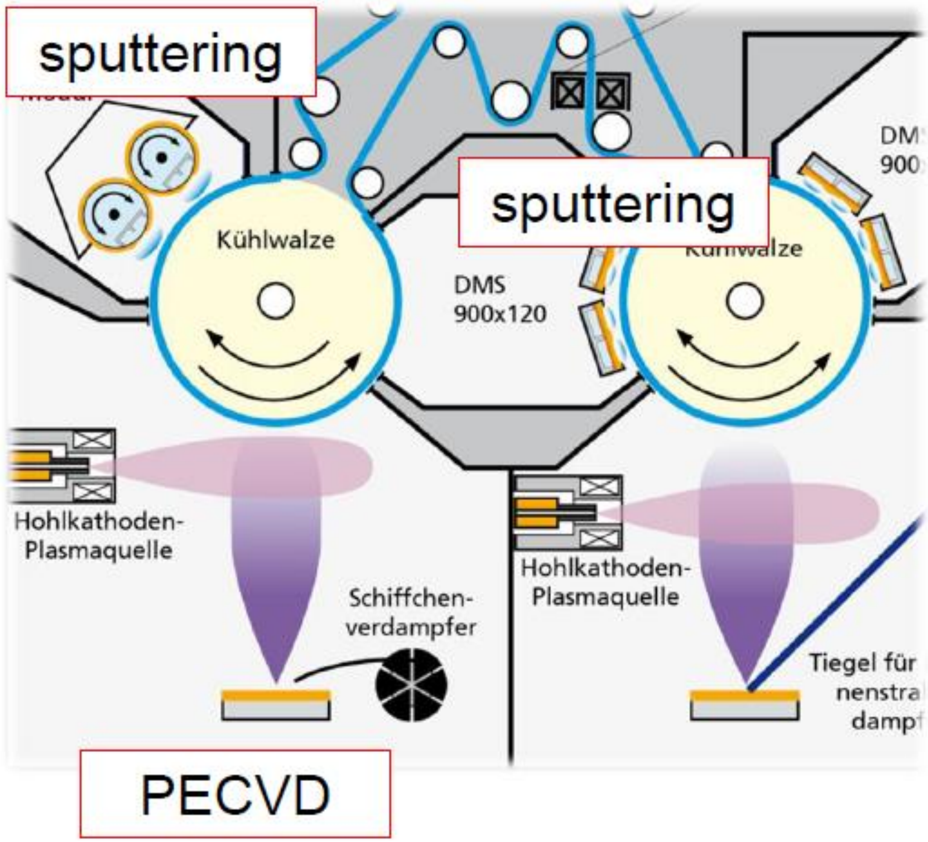
- same plasma source usable for sputtering and PECVD
- deposition rate up to 400 nm·m/min

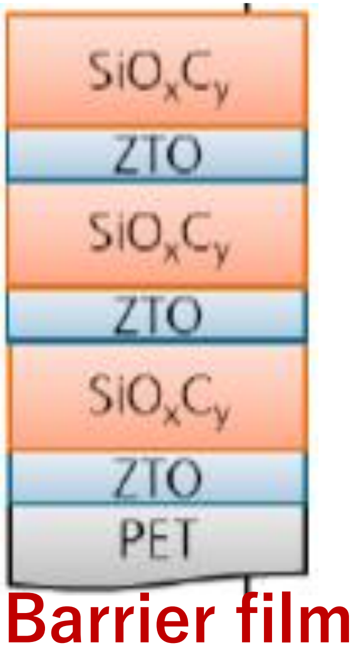
Hollow Cathode arc-PECVD

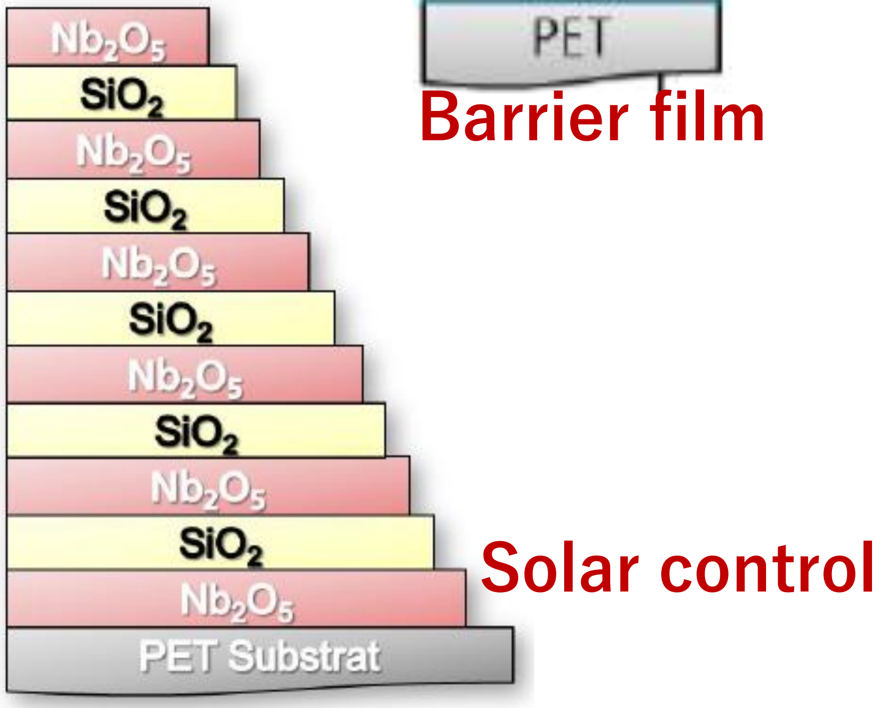
- high-density plasma
- deposition rate up to 2500 nm·m/min

- SiO_2 and $SiO_xC_yH_z$ plasma-polymer layers using HMDSO
- process pressure < 1 Pa
- inline compatible to reactive sputtering

Application of magPECVD and arcPECVD







- inline compatible processes
- high deposition rate with PECVD possible
  up to 500 nm·m/min for SiO_2
  up to 3000 nm·m/min for Plasmapolymers

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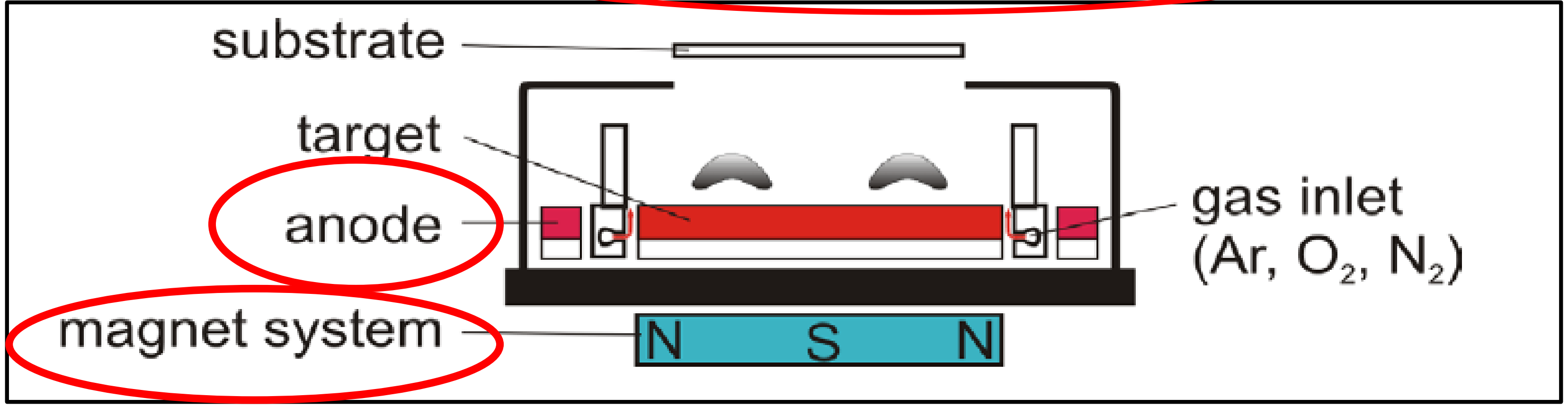
3, FEP's RM sputtering technology

with pulsed powering & process control

DMS
C-mag

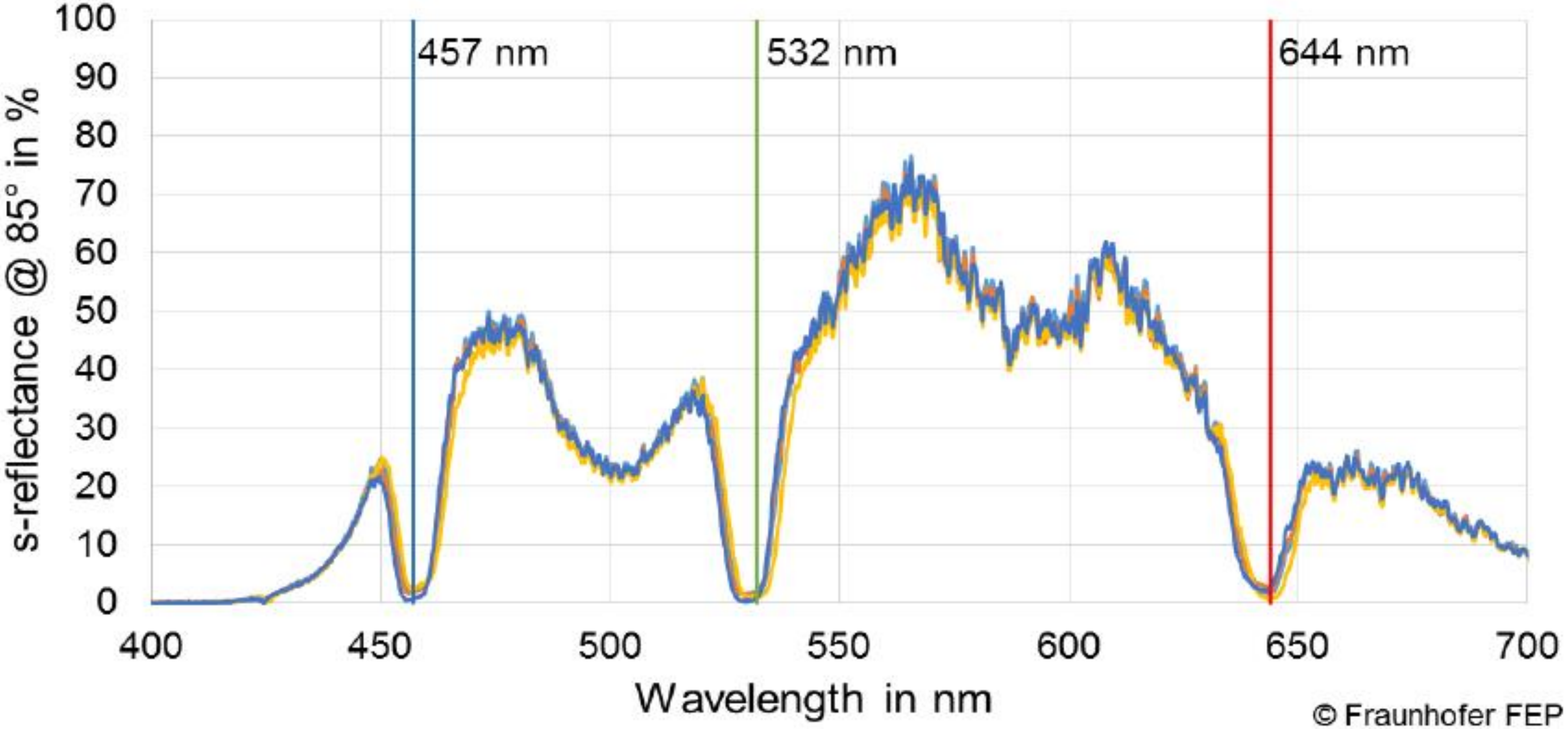


1. High rate
2. Excellent uniformity <+-0.5%
3. Long term stability
4. Low temp. & Low damage

1. Large area precision optics
2. Thin film encapsulation for OLED
3. Inorganic barrier film
4. Plastic substrate

Anti reflective (AR) coating for back-light of holographic display

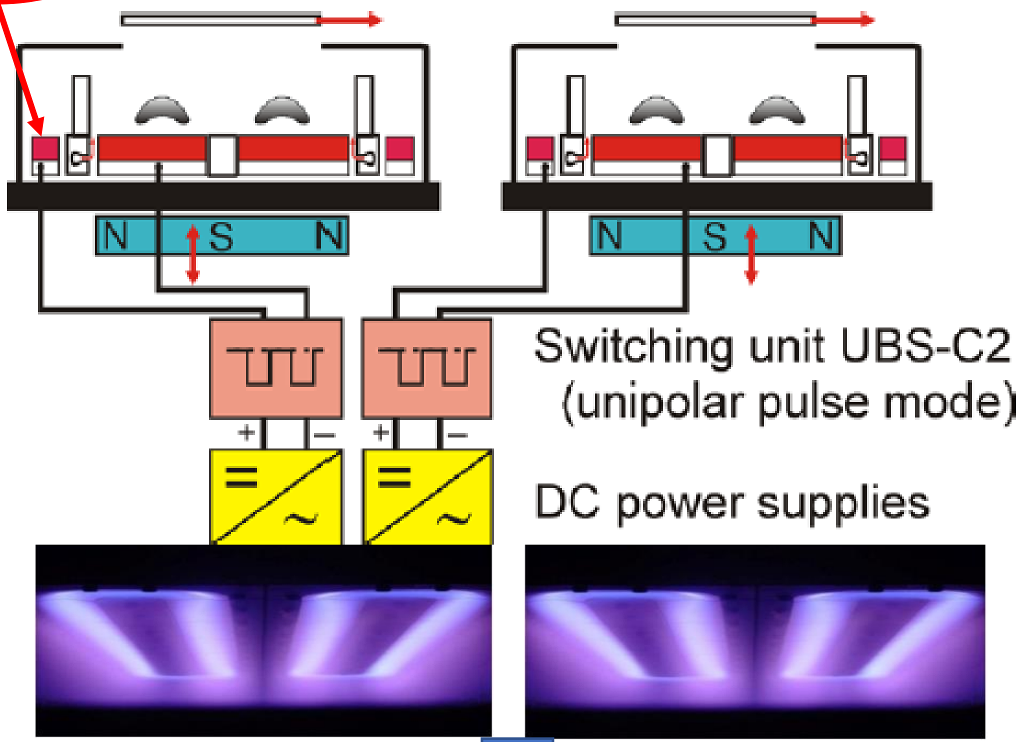
RGB AR coating:
Measurement of s-Reflectance @ 85° angle of incidence, center + edges of 20“ substrate (300x400 mm)



Pulsed powering in RM

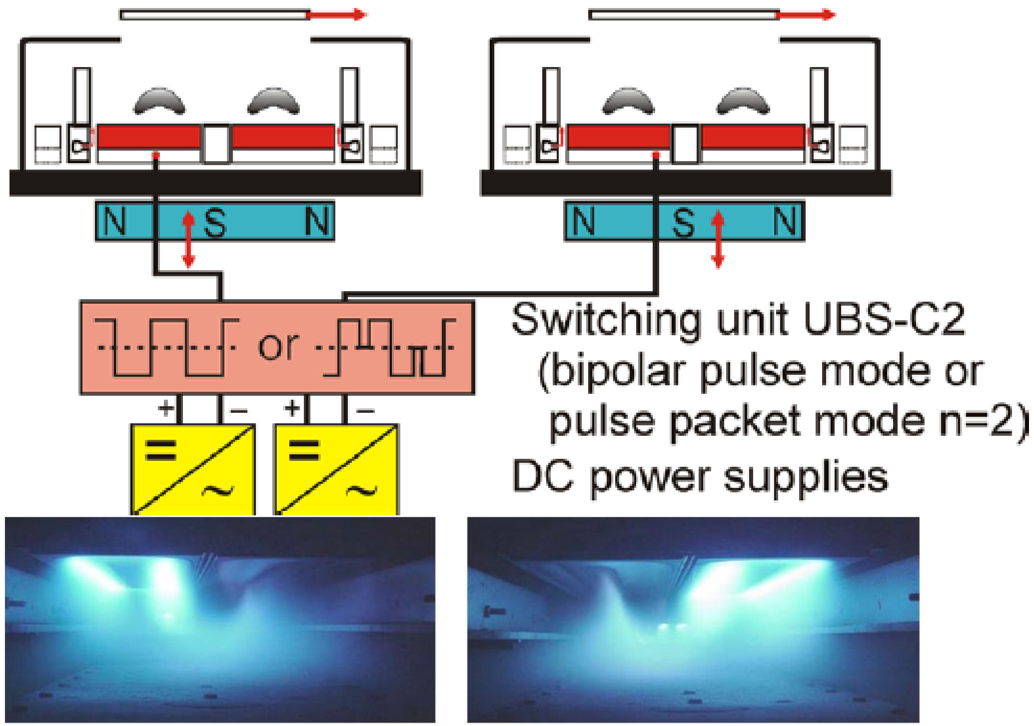
Hidden Anode

Unipolar mode



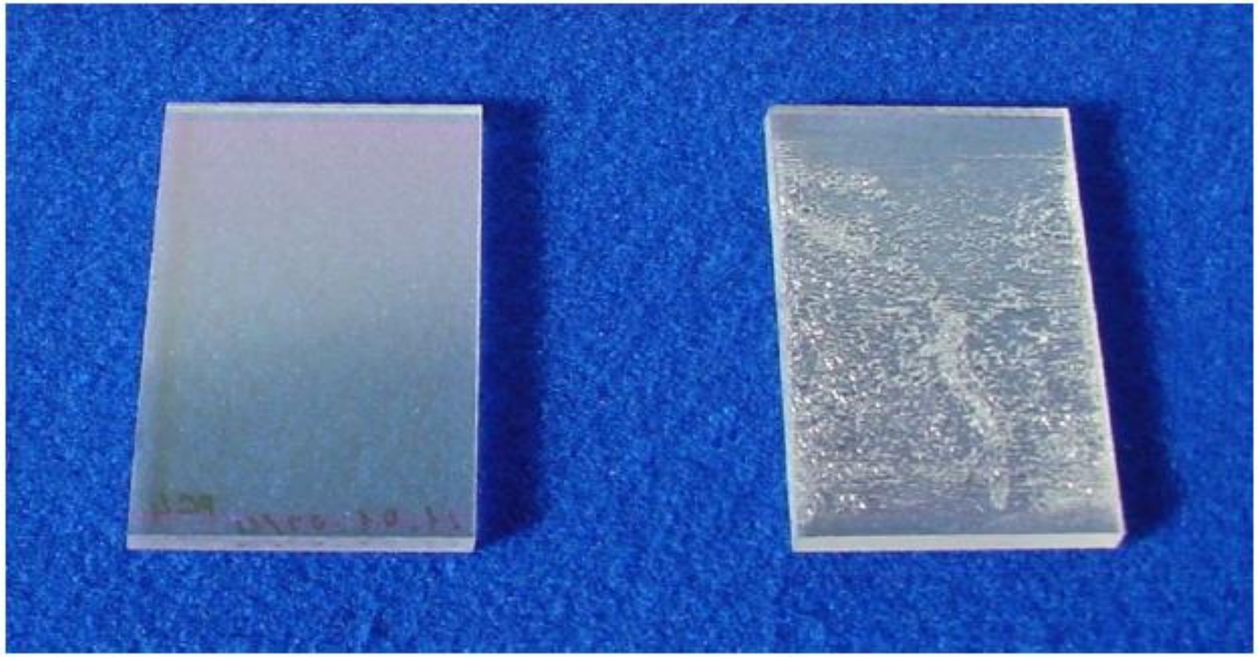
Low temperature
Low damage

Bipolar mode



High ion bombardment,
High thermal load

Energetic substrate bombardment in unipolar and bipolar pulse mode



- Substrate: polycarbonate (PC)
- Layer material: TiO_2
- Layer thickness: 500 nm

Unipolar

(T_{max}=143 °C)

- Better suited for coating on temperature sensitive substrates

Bipolar

(T_{max}=204 °C)

- Better suited for Deposition of very dense (stable) films

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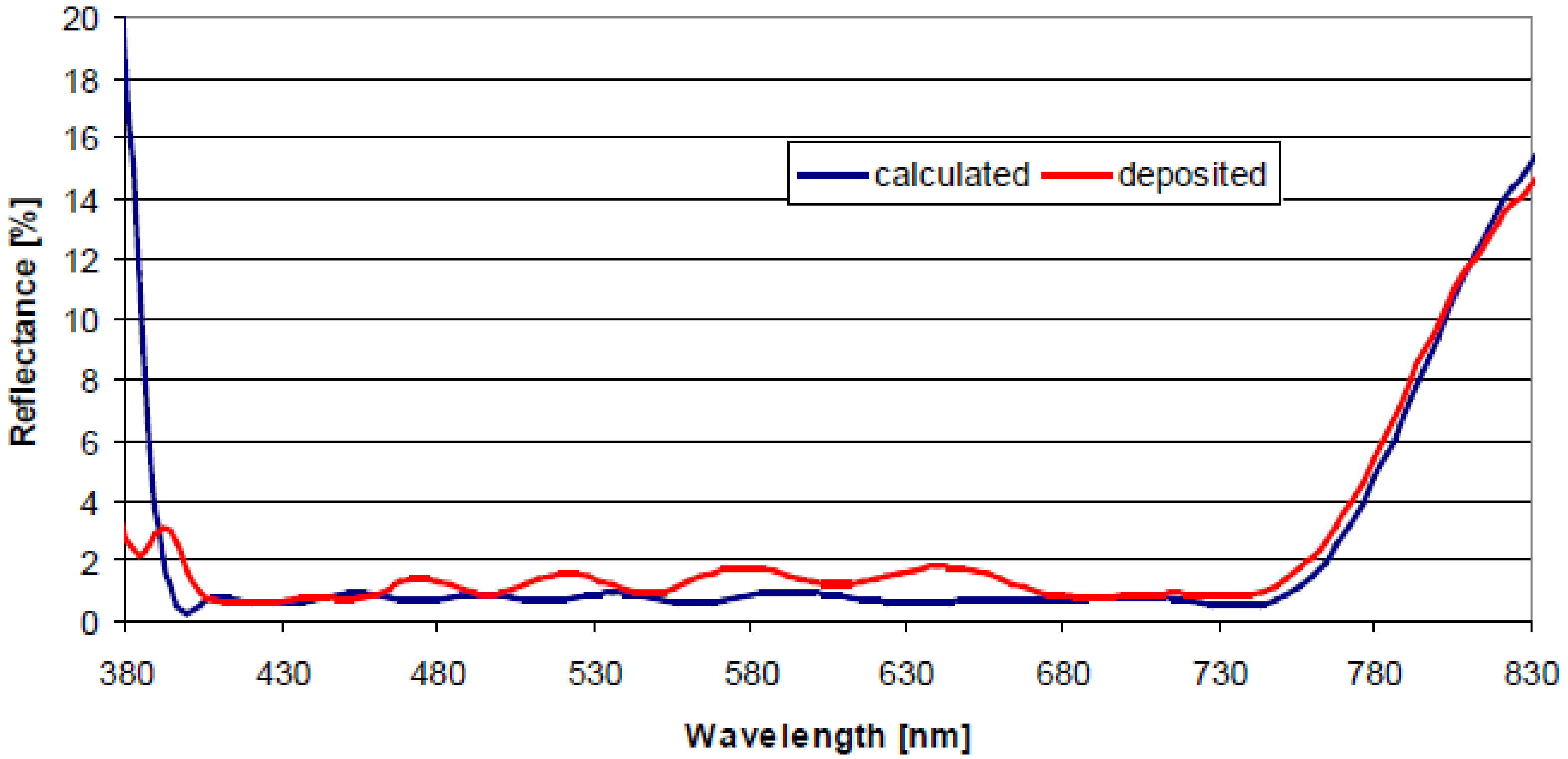
Broadband antireflection gradient coatings for plastic substrates (Design: AR hard®)

Collaboration with IOF, Jena

Design: Dr. U. Schulz

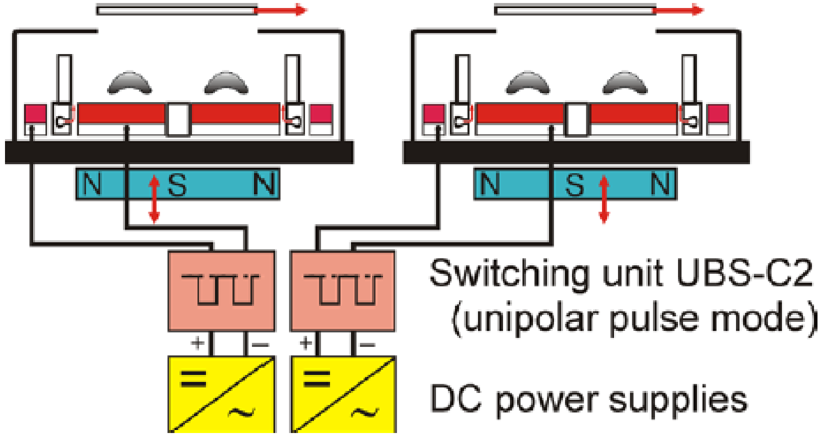


Reflectance spectrum of an AR-hard coating system with

- 17 layers (SiO_2/Si_3N_4) applied on both sides of a PC-substrate
- total thickness 1.8 µm

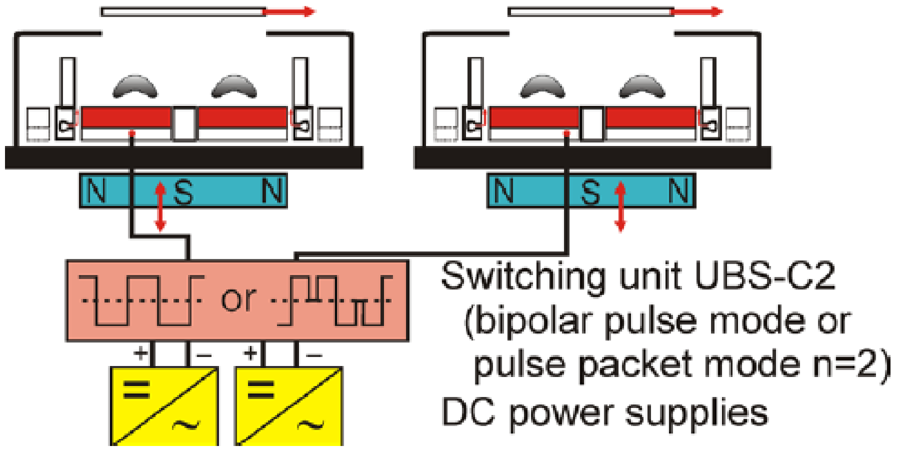
New approach to adjust film property in RM

Unipolar mode



Switching At 1kHz

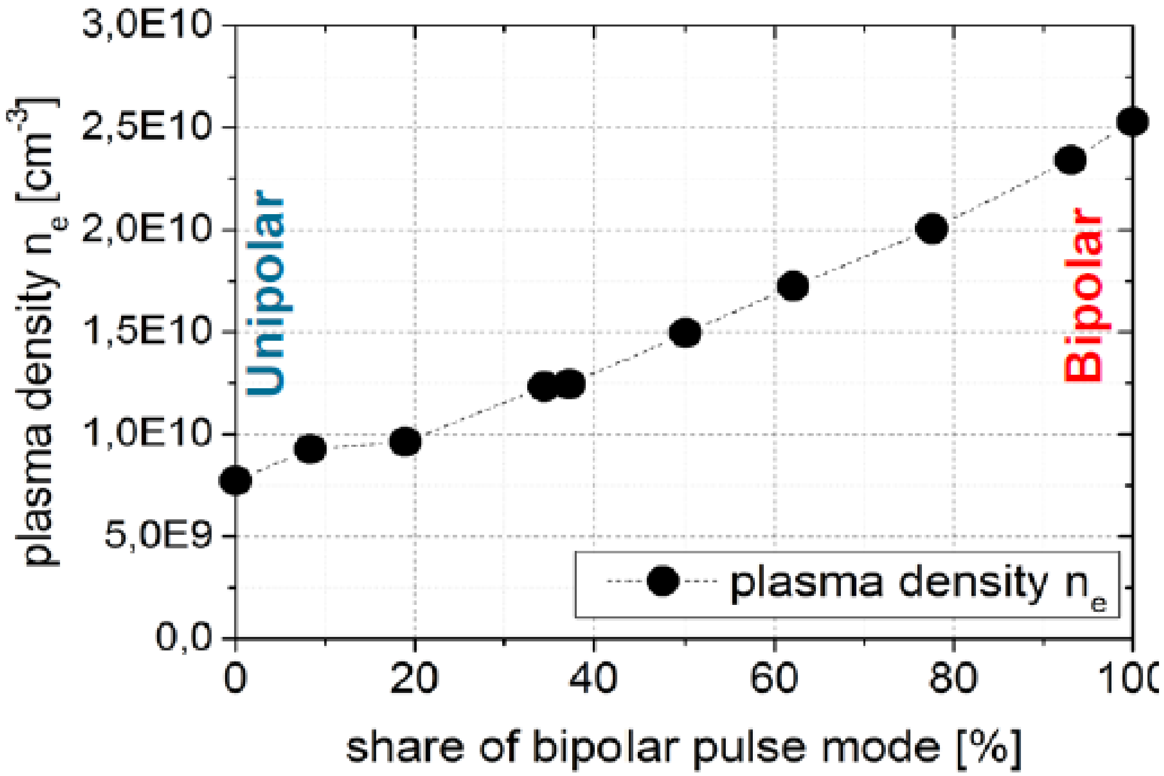
Bipolar mode

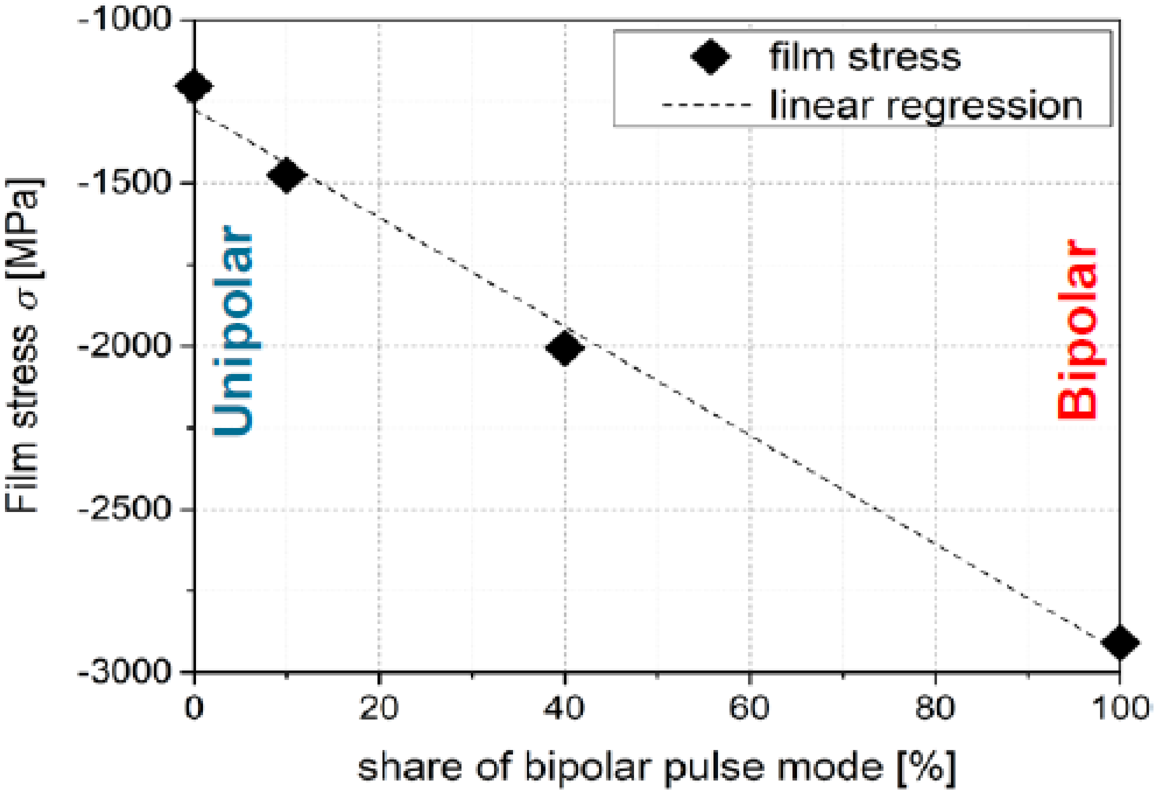


Unipolar pulse mode	U/b hybrid pulse mode	Bipolar pulse mode
moderate	intermediate	strong
bombardment of the growing thin film by high energy particles		

Hybrid Pulse Mode

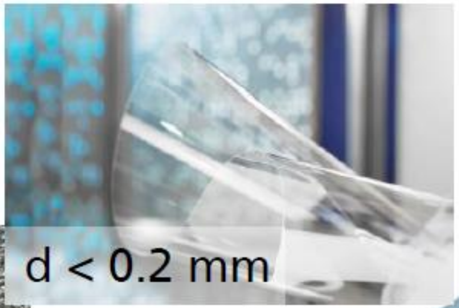
Plasma density & film quality control independent from the input power !!

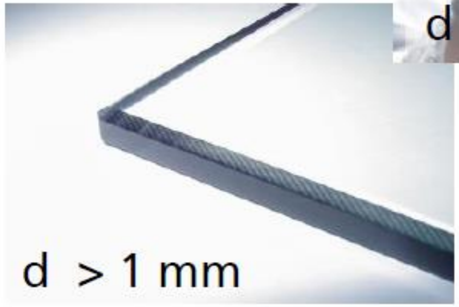




Coatings on flexible ultra thin glass

Progress in ultra-thin glass (UTG) product development





Ultra-thin glass

- Glass manufacturer

Coatings

- Equipment S2S, R2R
- Processing
- Handling
- Cutting

Products

- Lighting
- Display
- Sensors
- Energy storage
- Automotive

Corning, Schott, NEG, AGC, etc. **~30μm t**

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Example – AR Coatings on ultra-thin flexible Glass

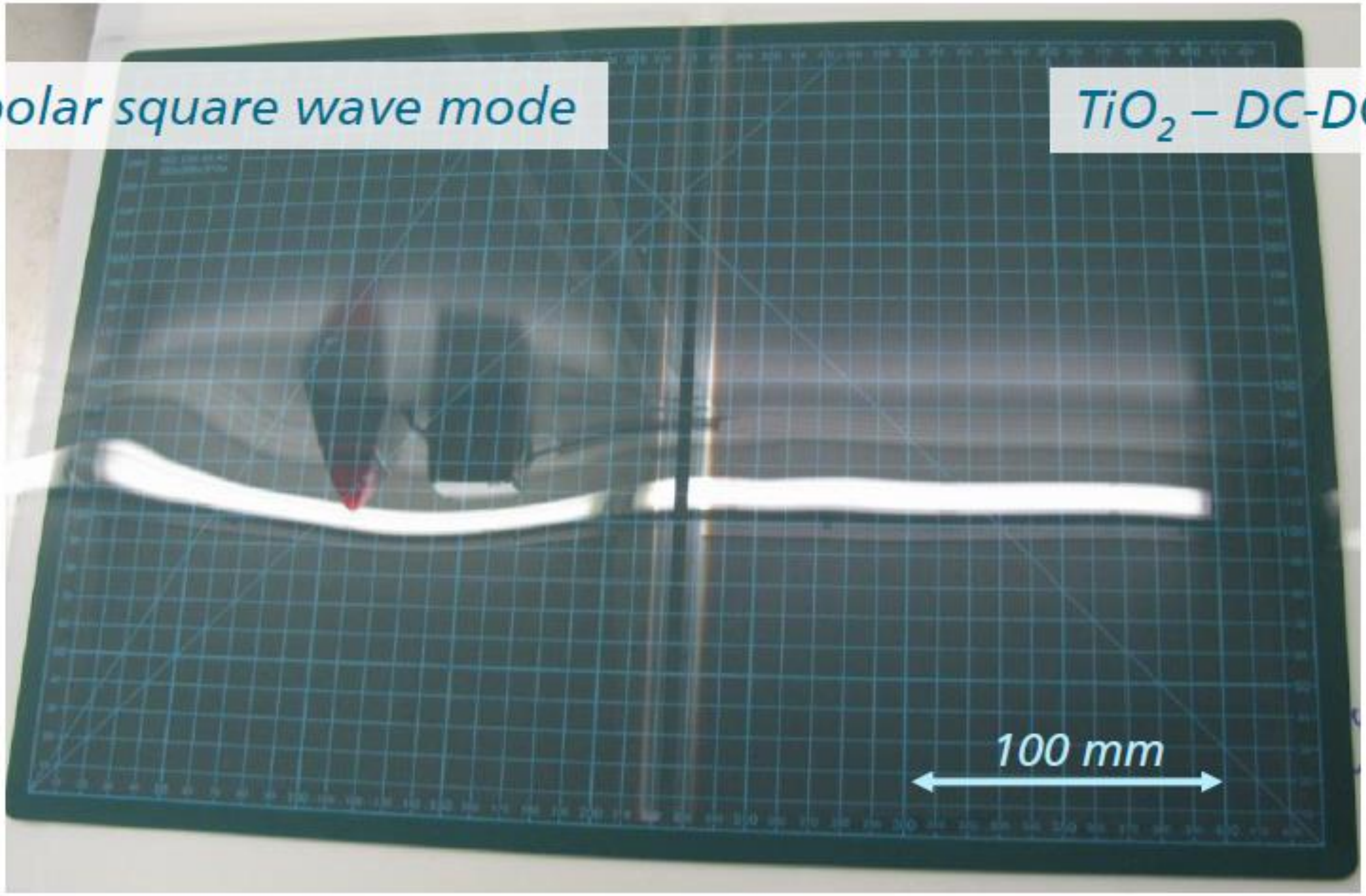
Anti-reflective coating on 50 µm flexible glass

Example – AR Coatings on ultra-thin flexible Glass

Only one side is coated!!!

TiO_2 – bipolar square wave mode

TiO_2 – DC-DC mode

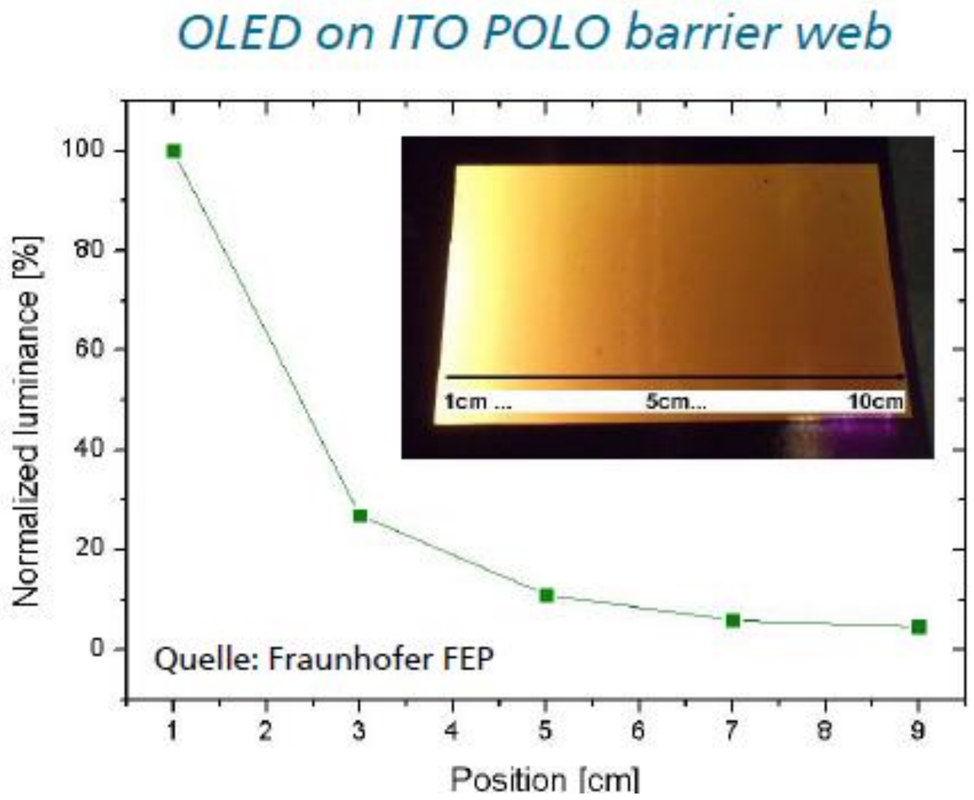


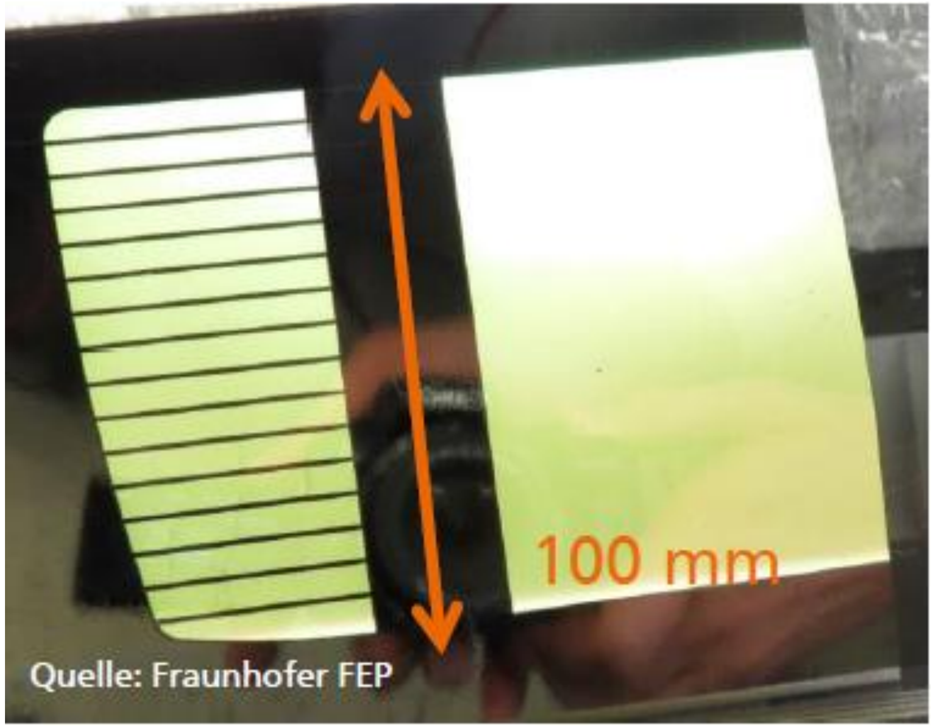
film stress layer stack: -175 MPa -75 MPa

TCO electrode for flexible OLED lighting

POLO film (PET)+ITO(35Ω/sq)
➔ 90% reduction in brightness

Ultra thin glass+ITO(12Ω/sq)
➔ Uniform brightness in 10cm2

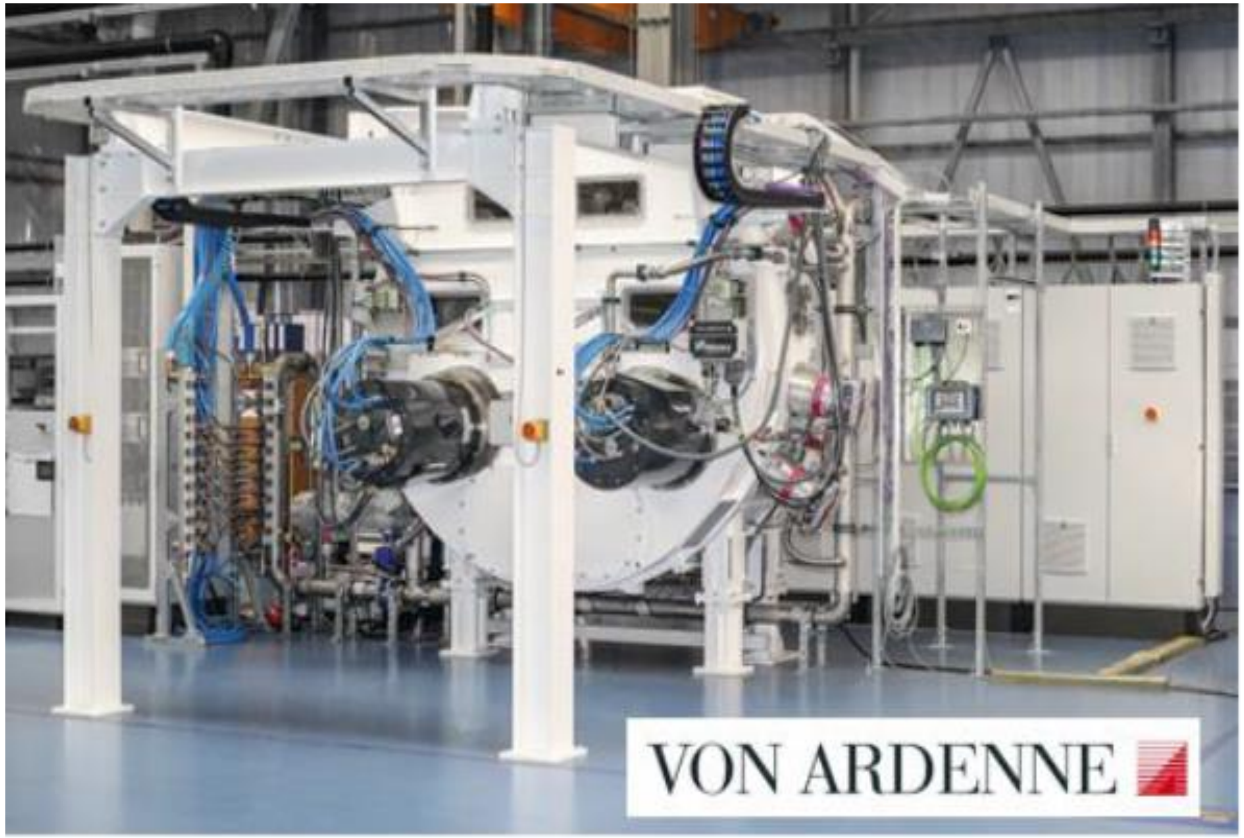




Vacuum R2R coater for flexible ultra thin glass

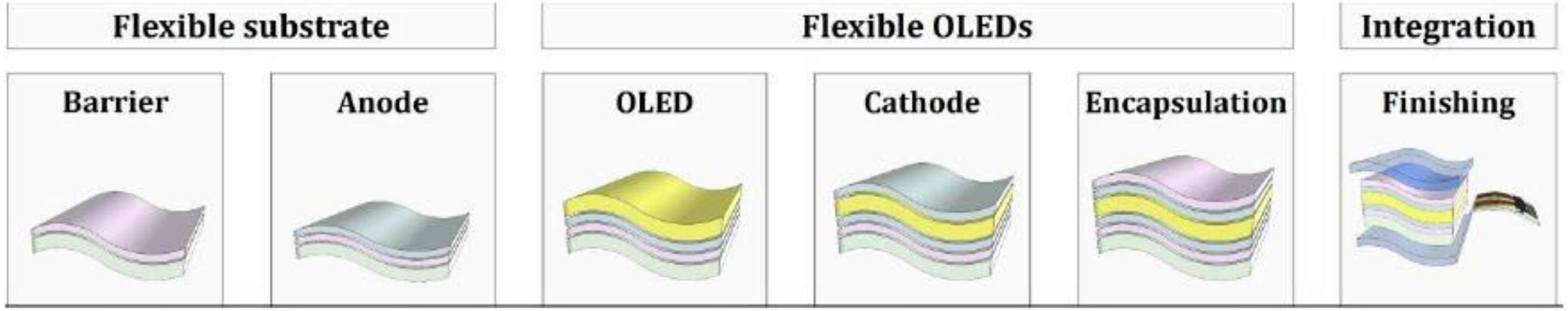
*Substrate width: 330mm
*Heating: < 350℃
*Thickness : >50 μm

*4 coating zones
*Dual anode sputtering
*Front-side touchless



Flexible OLED lighting

Portfolio of the Division Flexible Organic Electronics



Flexible Organic Electronics

- S2S sputtering for electrode (up to 370x470mm²)
- S2S layer deposition via printing, slot die coating, spin-coating
- S2S OLED deposition by evaporation (up to 200x200mm²)

- R2R barrier web
- R2R magnetron sputtering for electrode deposition
- R2R structuring via printing
- R2R-OLED deposition
- R2R lamination

- Laser ablation
- Laser cutting
- Laser structuring

OVERVIEW PROCESS FLOW IN R2R R&D LINE

R2R inspection system

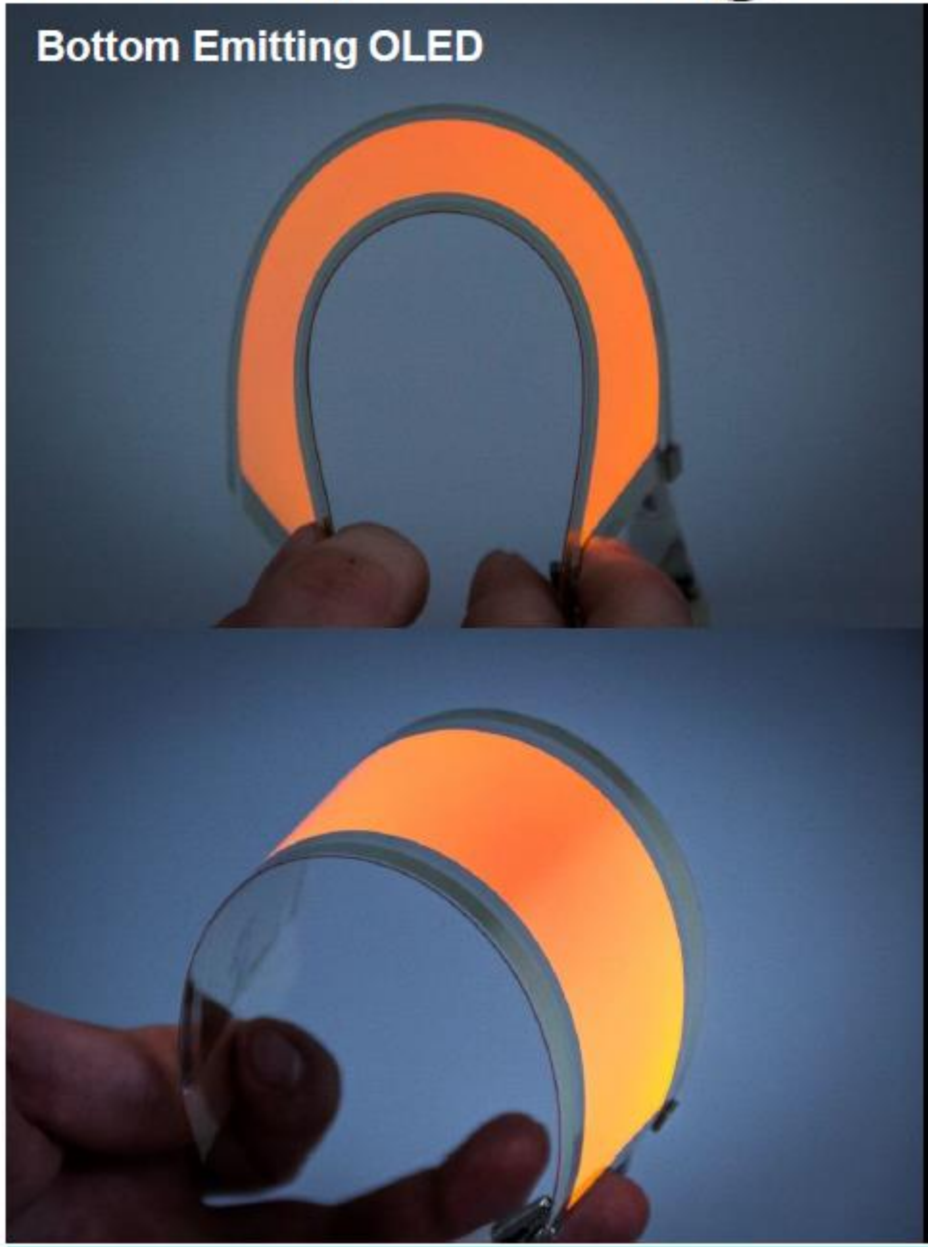
R2R vacuum coater

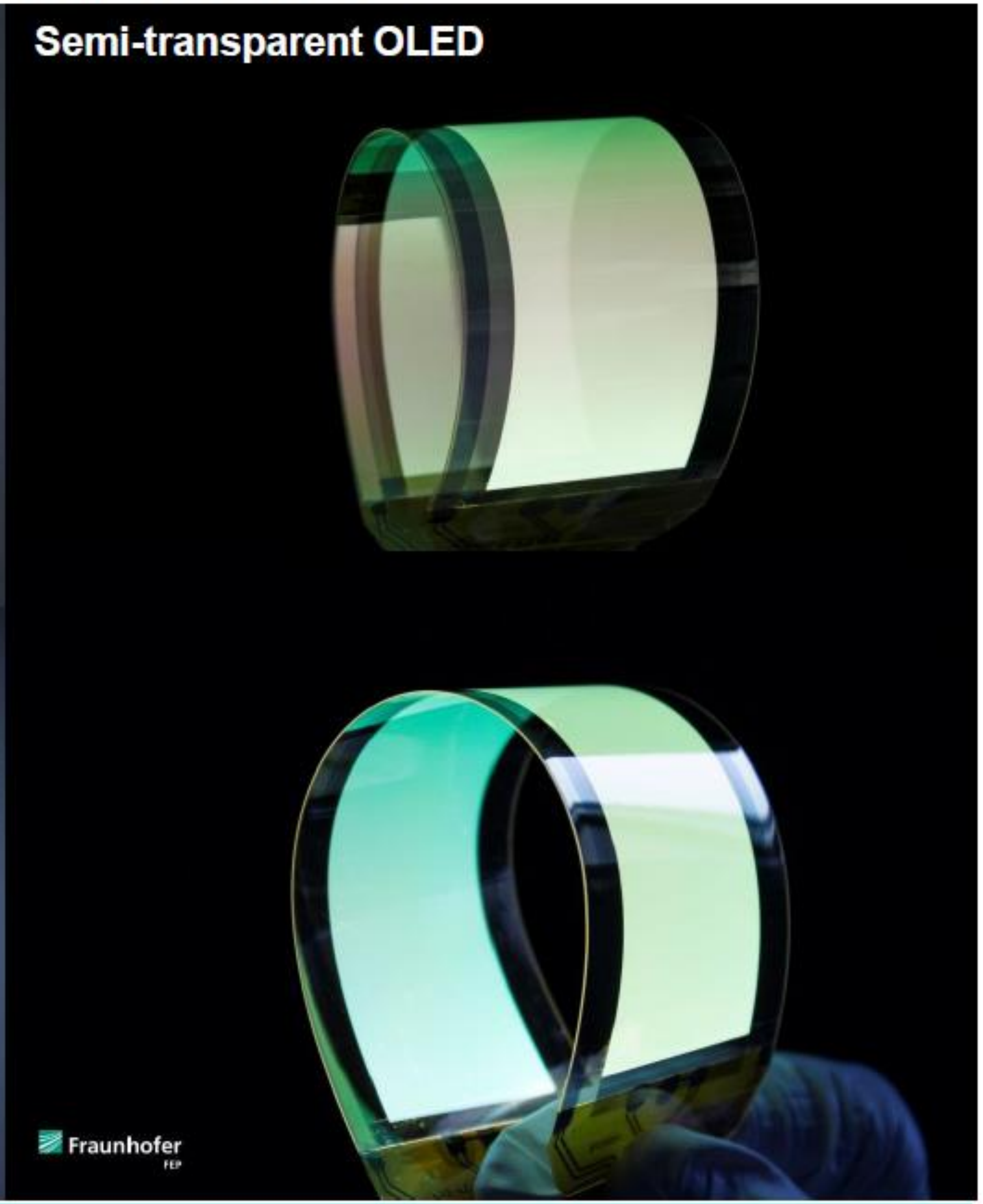
R2R printing and lamination unit (N_2)

Substrate Inspection → Structuring → Substrate inspection → Vacuum coating → Encapsulation → OLED characterisation

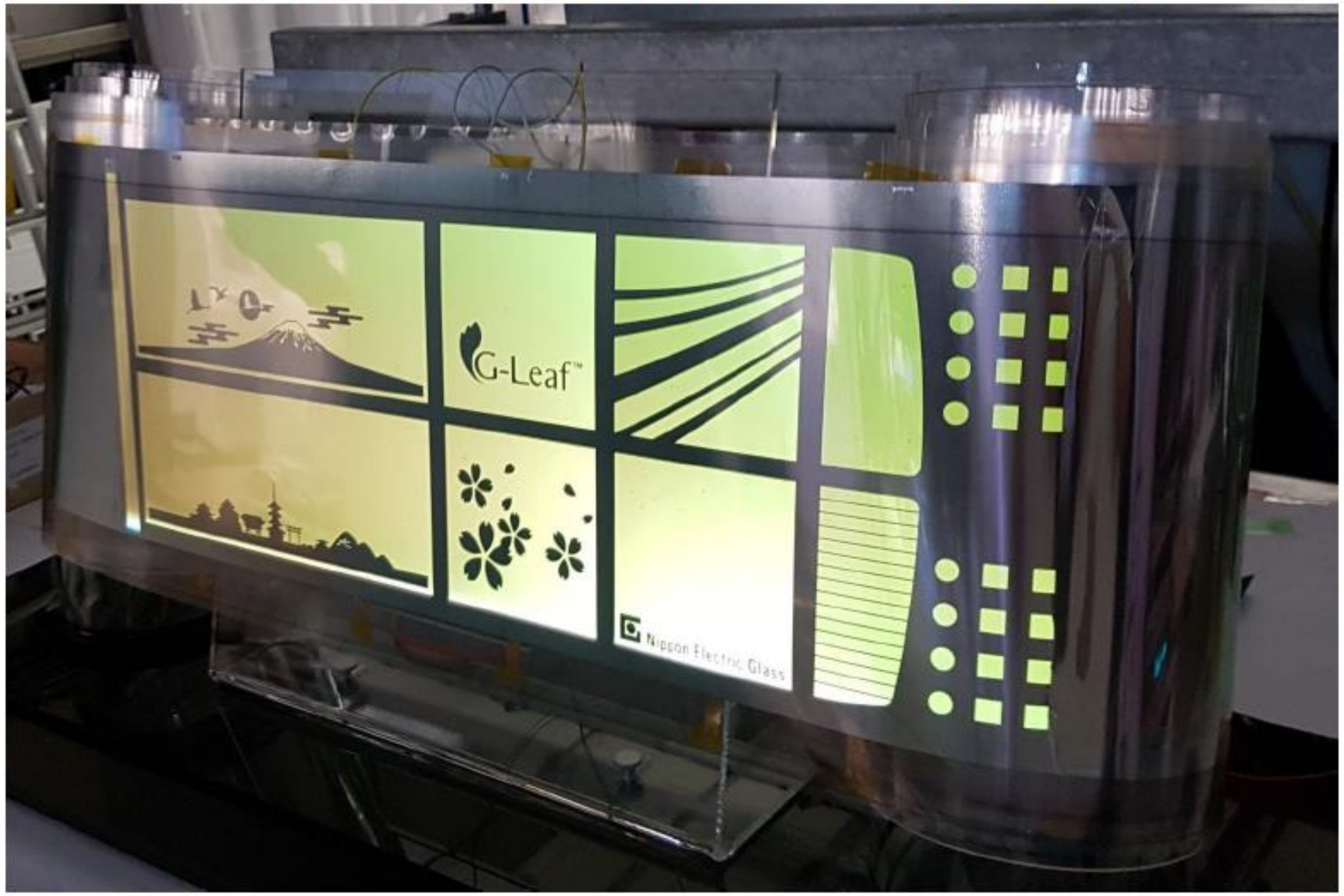
- Typically **300 mm** web width
  - metal strips: thickness up to 500 µm
  - **polymer webs : thickness 50 to 500 µm**
  - **flexible glass : thickness 50 and 100 µm preferably ("pure" or laminated on PET)**

OLED on plastic foil @ Fraunhofer FEP





R2R OLED ON ULTRA THIN GLASS
ENCAPSULATED WITH ULTRA THIN GLASS (50 µm)



Demonstration of 25 x 10 cm² OLED devices without dark spot growth!
Challenge: Development of proper cutting technology

G-Leaf™ Collaboration with GLASS FOR FUTURE Nippon Electric Glass

Fraunhofer FEP

Fraunhofer FEP

SurFtechTransnational

Current challenges in flexible OLED with plastic barrier film

How to stop black spot formation!!

Factors to affect on OLED life：

WVTR + ＊**Residual water and drying method**

＊Particles

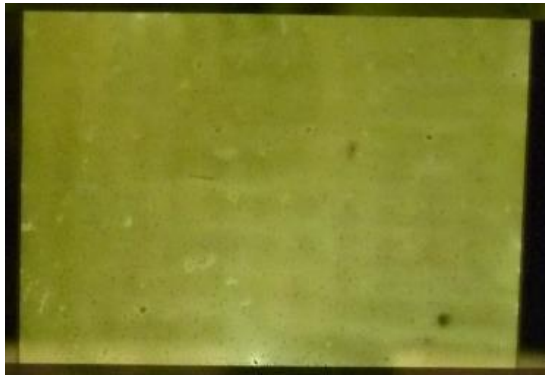
＊Handling and mechanical strength

＊Residual stress, adhesion

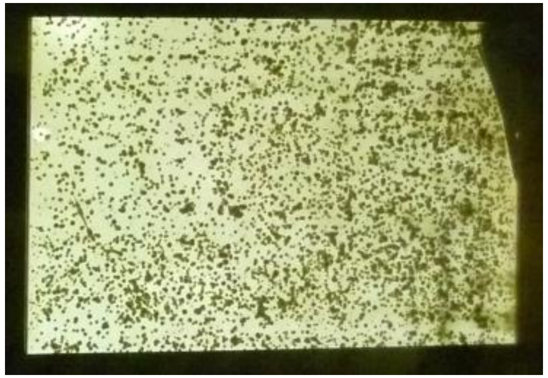
＊Residual organic solvent & reaction

＊Device structure & optical property

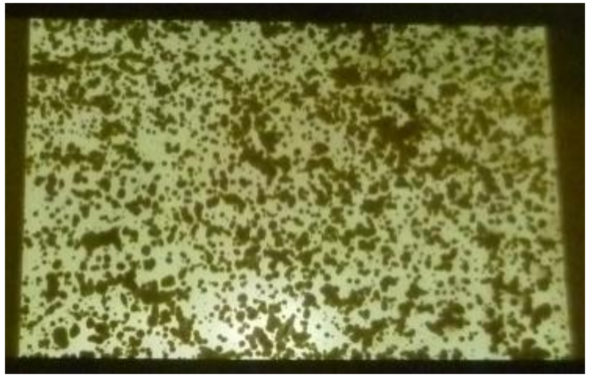
Ex.： Effect of vacuum drying of barrier film on OLED life



80°C、1 week



80°C、160hrs



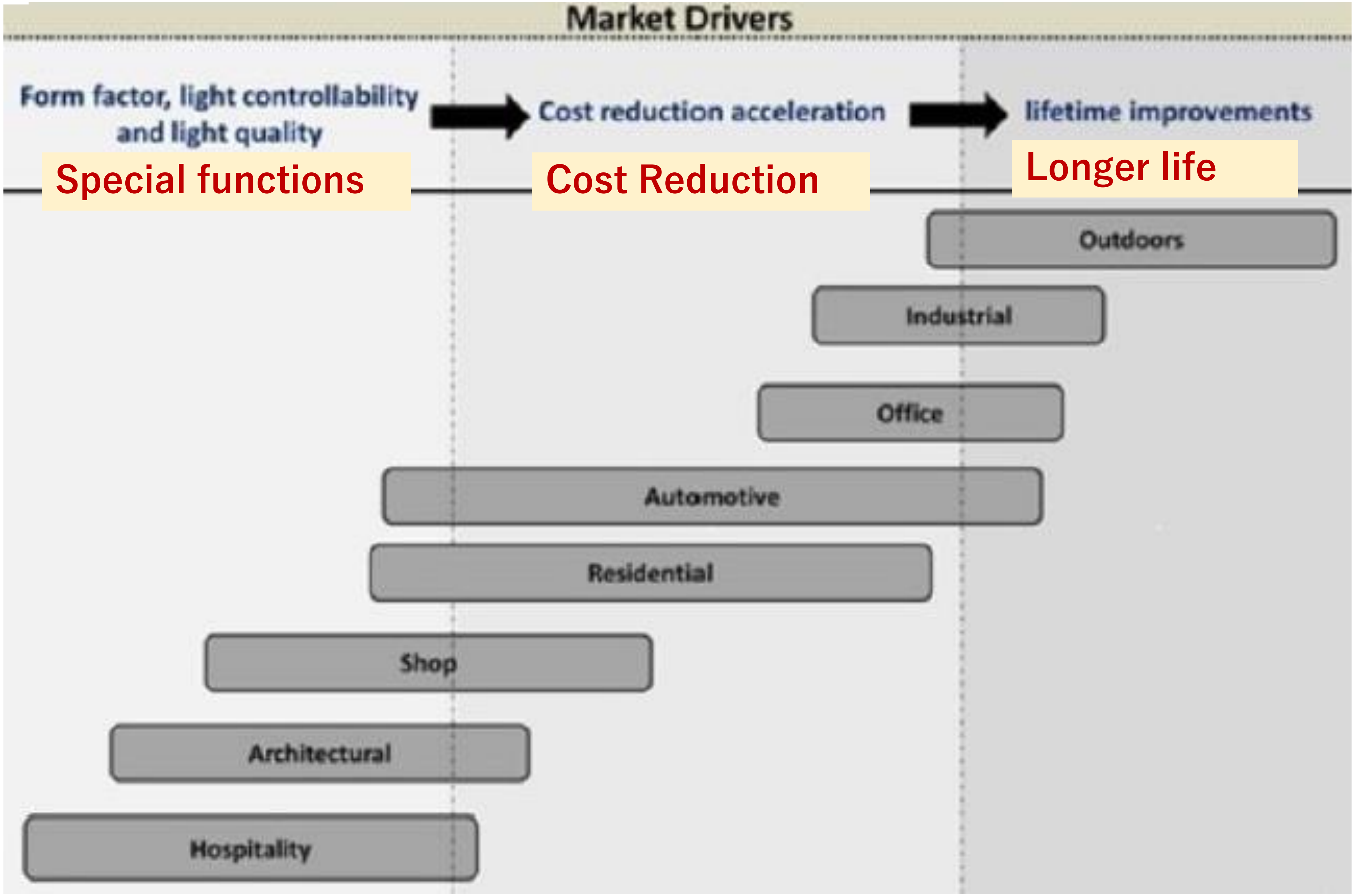
80°C、100min

OLED APPLICATIONS

OLED Application

- Consumer Electronics
  - Smartphone
  - Notebook
  - TV
  - Camera
  - Media player
- Signage
  - Buttons
  - Signs
- Automotive Lighting
  - Tail
  - Interior
- General Lighting
  - Luminaires
- Others
  - Medical app.
  - Wearables
  - Packaging

Display | Lighting and signage


Market Drivers
Form factor, light controllability and light quality
Cost reduction acceleration
lifetime improvements
Special functions
Cost Reduction
Longer life
Outdoors
Industrial
Office
Automotive
Residential
Shop
Architectural
Hospitality

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OLED Luminaires

Innovation vs. Preis

Necessity of killer application!!

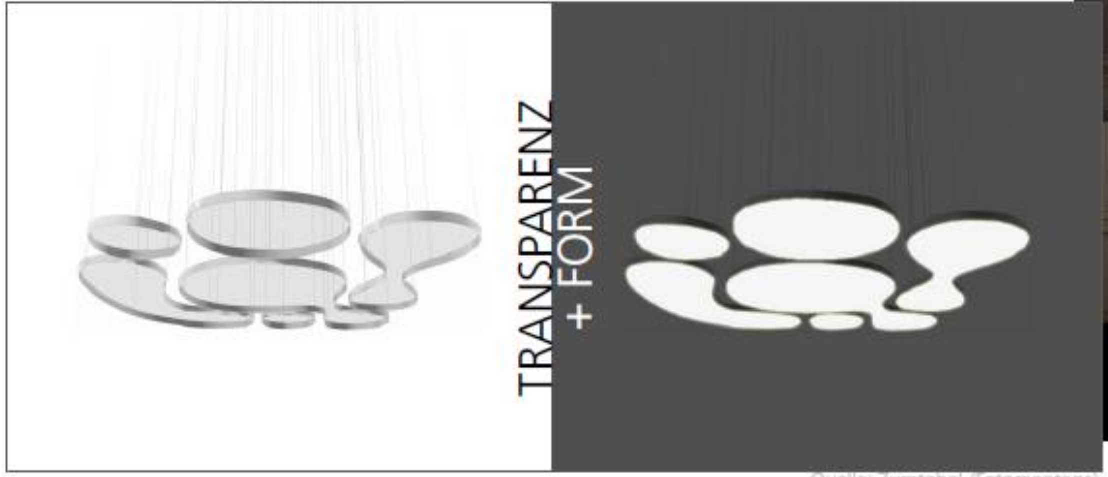
Current status:
~~Standard-OLED Module → Luminaire~~

Goal:
„shapeable"-OLED = luminaire

(Exceptional: Hybrid-Luminaire LED/OLED)

Quelle: Tom Dixon

Quelle: Marcus Tremonto



Quelle: Zumtobel (Fotomontage)

Application scenario automobile

Short-term:
OLED Integration in back lights
→ 3-dimensional distribution of rigid glass OLED devices or
flexible OLED-module in lighting bodies (complemented with LED)

Quellen: Hella; Bimmerpost

OLED backlight in Audi TT: http://www.audi.de/de/brand/de/neuwagen/tt/tt-rs-coupe-tt-rs-roadster.html#

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Application Automobile

Long term:
Interior lighting

→ Large area transparent OLED lighting in the roofs
→ e.g. Smart Forvision Study with BASF

A dream for designers:
Lighting in the car body

→ Lighting contours for recognition at night
→ Removing of classical headlights
→ e.g. Study from Audi

For visual communication with humans !!

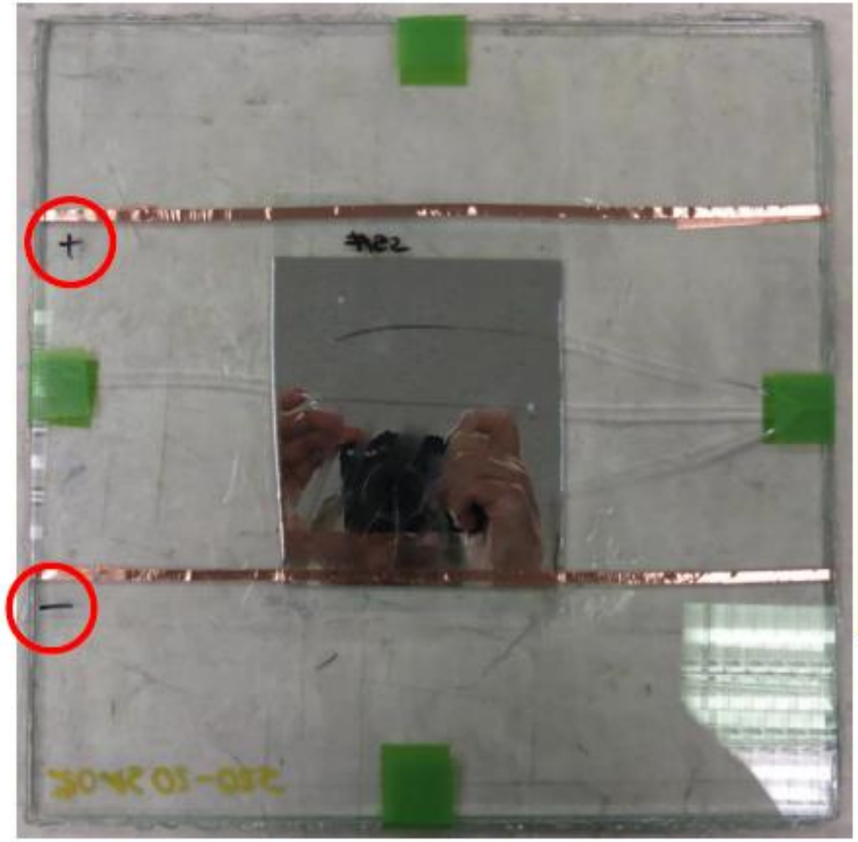
Quellen: Smart/BASF; Audi

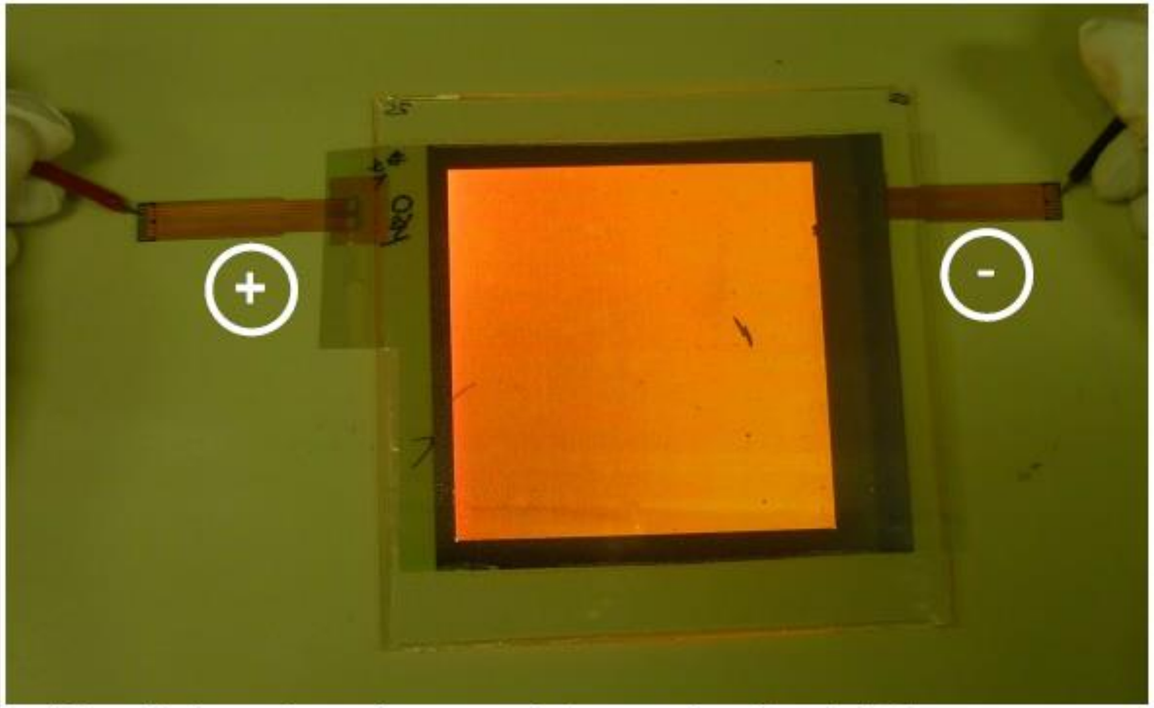
Technological trends: OLED/OPV-Integration into Glass laminates

- OLED – first demonstrator
  - Integration in room separator (St. Gobain with LG Chem on Light&Building 2014)
  - Integration opaque modules (rigid glass) in a shelf (Glas Trösch with LG Chem on Light&Building 2014)
- Building integration of organic photovoltaic (BIOPV)
  - Heliatek in Singapur (Mai 2015): HeliaFilm® into glass roof (15% and 30 % transparency) in different color.

Flexible OLED on plastic barrier film in glass laminates

300x300 mm Glasscheiben





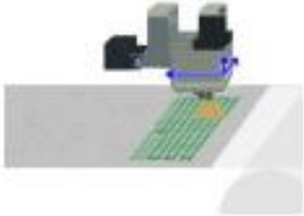
„Hot“ lamination at Fraunhofer FEP at 130°C, pressure 5 bar. Electrical connection by ACF bonding of polyimide flex cable.

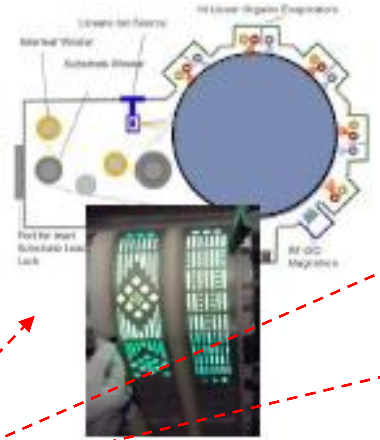
OLED on plastic barrier film in glass-glass after autoclave process < 100 °C. Electrical connection using copper tape.

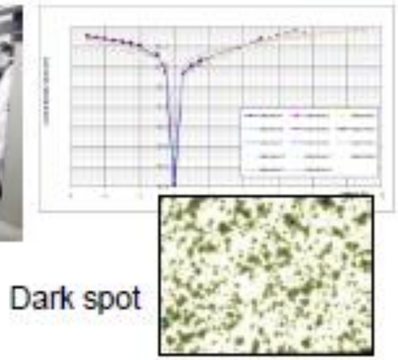
Collaboration with Japanese companies

Evaluation of barrier films using FEP’s OLED pilot line

Defect
Water content → Patterning → Deposition → Lamination → Life test
Storage test
Defect check
Performance







Japanese barrier film manufacturers

Other collaborations with Japanese companies

1. Test coating of FEP's barrier layers on the customer's substrate
   ex. ZnSnOx by sputtering

2. Test coatings to evaluate FEP's key component
   ex. magPECVD, HAD, RM

3. Introduction of key component
   ex. RM with process control & pulse power supply,
   magPECVD, HAD

4. Development of new products using FEP facilities

Summary

*FEP covers from coating to OLED device manufacturing

- -Material and layer stack development
- -Process & hardware development
- -Evaluation of customers products
- -Device development
- -**Technology package with hardware!!**

*There are many available pilot or production technologies which might be useful also for **GPD participants!!**