VACUUM BASED ROLL-TO-ROLL OLED COATING FOR PILOT LEVEL

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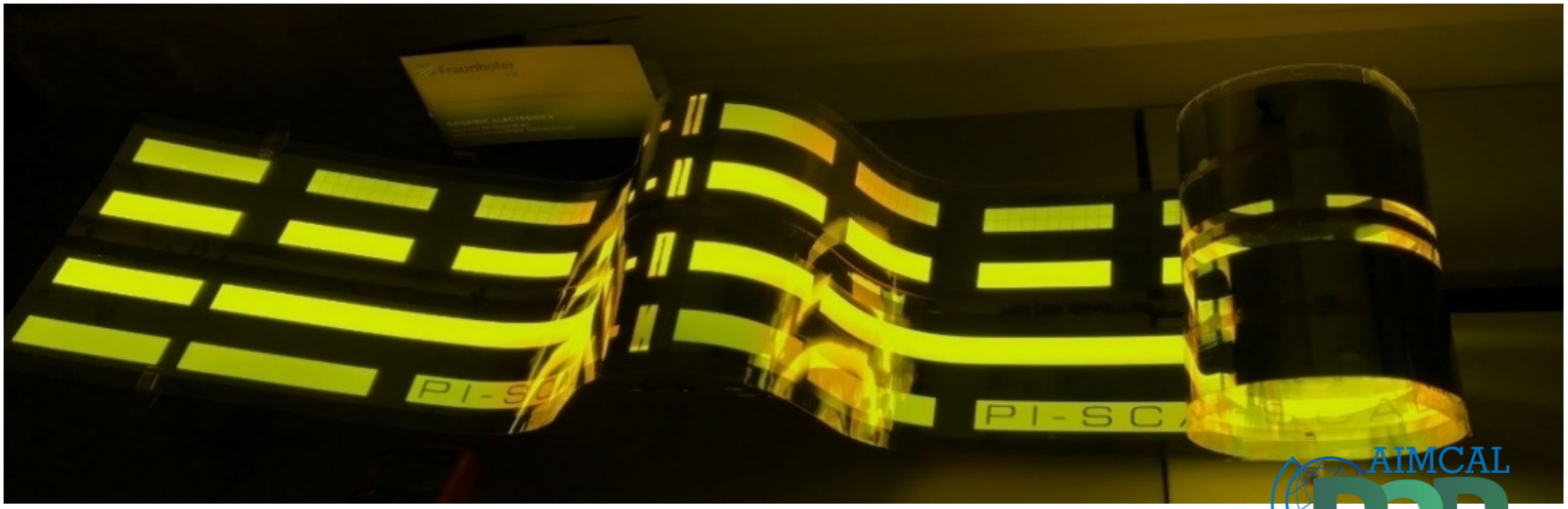

AIMCAL R2R Conference 2017, October 15 -18, 2017, Tampa, FL, USA

AGENDA

- Division Flexible Organic Electronics @FEP
- Flexible OLED lighting on different type of substrate
- Roll-to-Roll OLED manufacturing
  - Benefits
  - Roadmap for pilot scale
- Summary

PORTFOLIO OF THE DIVISION FLEXIBLE ORGANIC ELECTRONICS

- Customer specific R&D on novel device concepts and manufacturing methods for Organic Electronics (mostly small molecule)
  - mainly OLED lighting & signage, but also OPV, OPD und OFET
  - Flexible foil substrates (esp. Roll-to-Roll-technology) for flexible applications (rigid substrates also possible)
- Services along the full value chaine for (flexible) organic devices
- Process development
- Test of new materials
- Prototype development
- Device integration (electrical, mechanical)

200 mm System: Glass substrates , metal and polymer web, flexible glass up to 200 x 200 mm²

Gen2 Line: Glass substrates 370 x 470 mm²

R2R Line: Metal and polymer web, flexible glass up to 300 mm width

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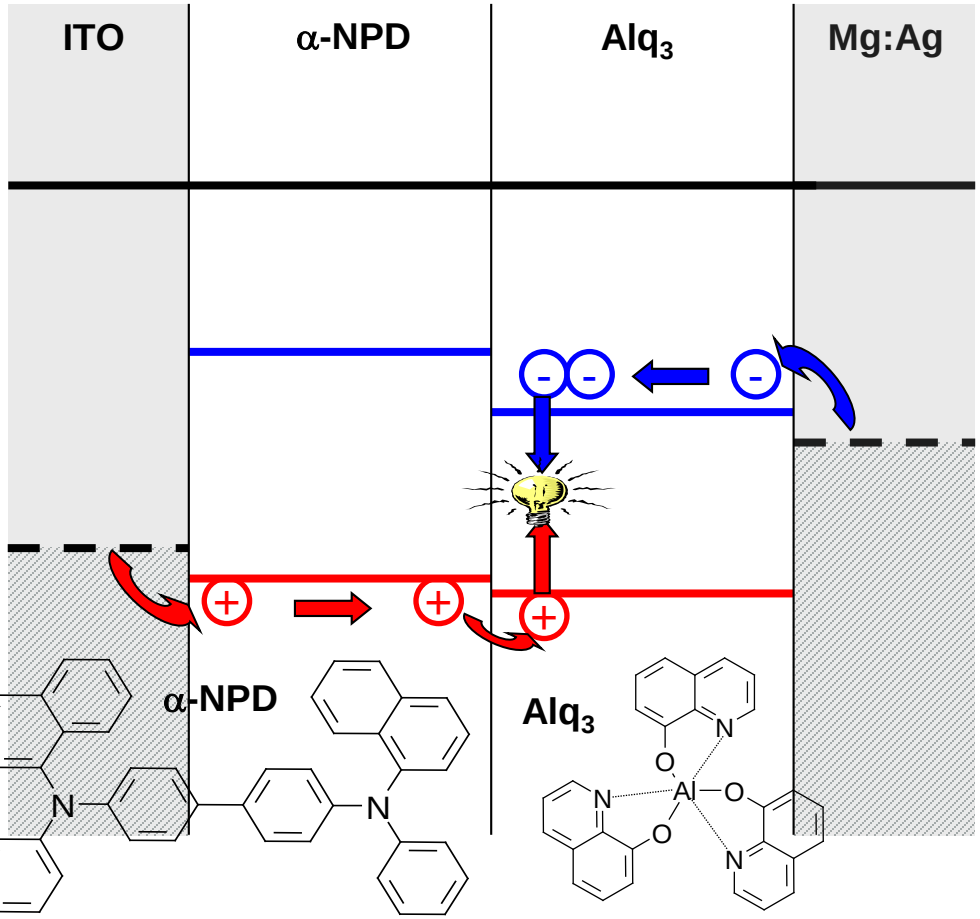
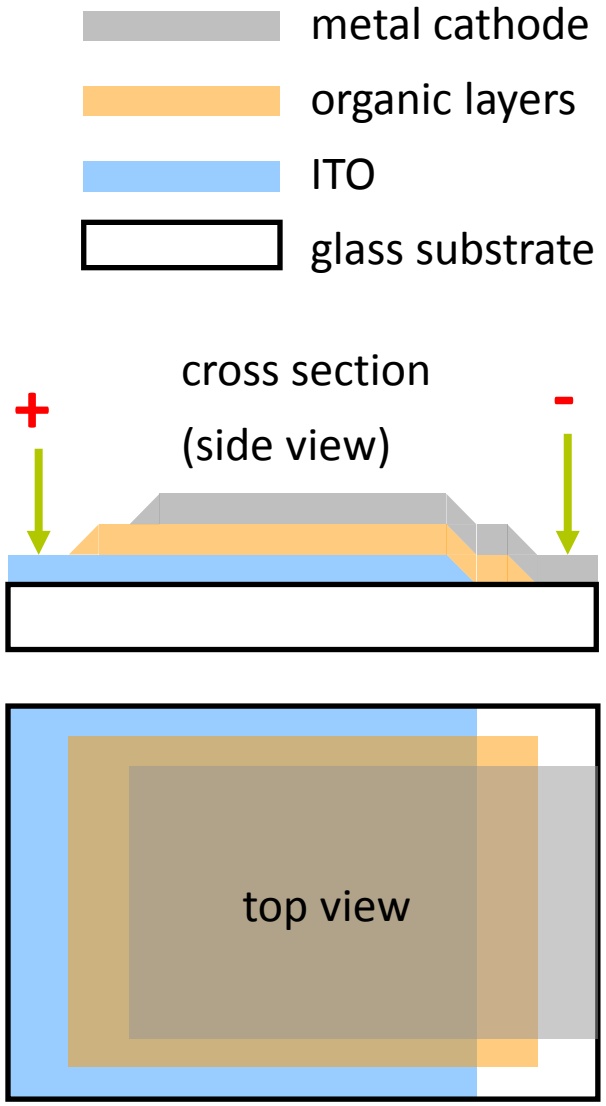
THE OLED: MOST SIMPLE

- 1987: 2 organic layers
- today: up tu 5…30 organic layers





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Why OLED?

Challenges:
Cost
Reliability

COMPARISON OF FLEXIBLE SUBSTRATES FOR OLED DEVICES

	metal	ultra-thin glass	plastic
bendability	o	o	√
permeation barrier	√	√	o
roll-to-roll processabilty	√	(√)	√
surface roughness	o	√	√
potential of low cost	√	???	???
advantages	good barrier thermal conductivity	good barrier surface quality transparency	transparency high bendability
disadvantages	top emission additional treatment of reducing surface roughness	brittle device separation	barrier coating thermal stability residual water possible pinholes

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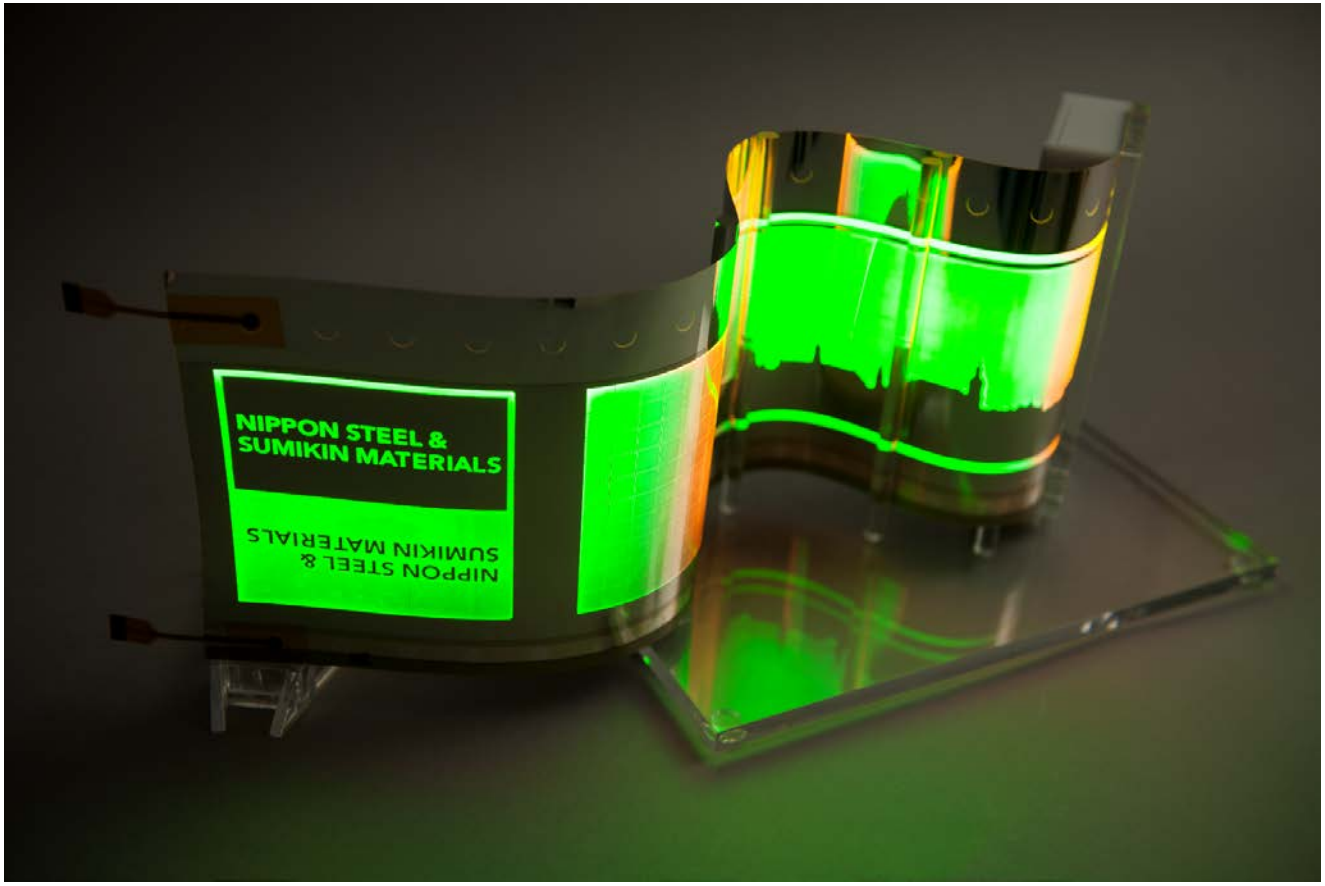
OLED DEVICES ON STAINLESS STEEL FOIL



OLED on 50 µm stainless steel foil development in collaboration with Nippon Steel Sumikin Materials.

新日鉄住金マテリアルズ株式会社
NIPPON STEEL & SUMIKIN MATERIALS CO., LTD.

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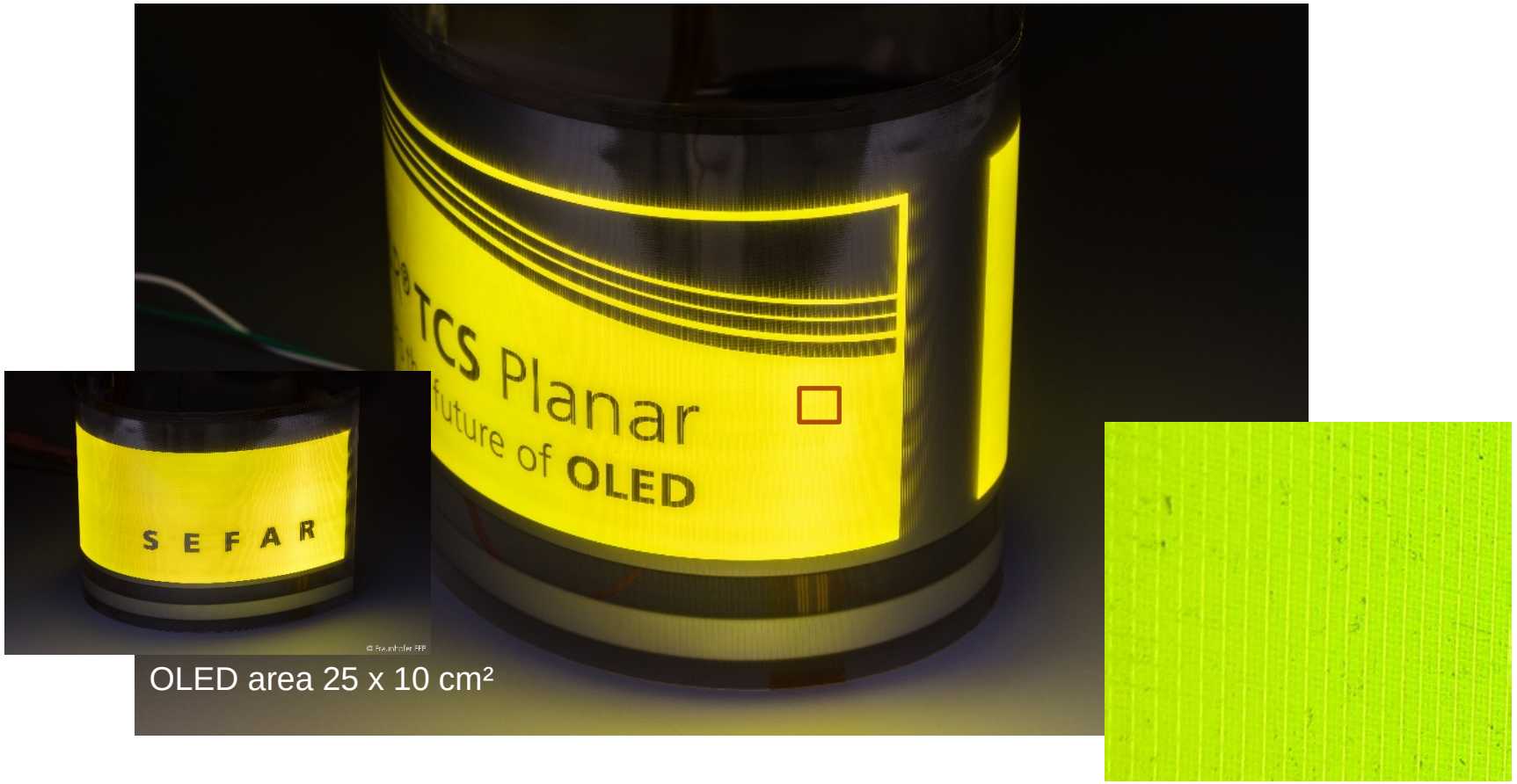
HIGHLY CONDUCTIVE POLYMER FILM FOR LARGE AREA LIGHTING



High conductivity embedded metallic wires result in a conductivity of 0.01 Ohm and in a transparency of about 90%. Electrode film and OLED embedded in a so called “Ravioli” approach.

SEFAR

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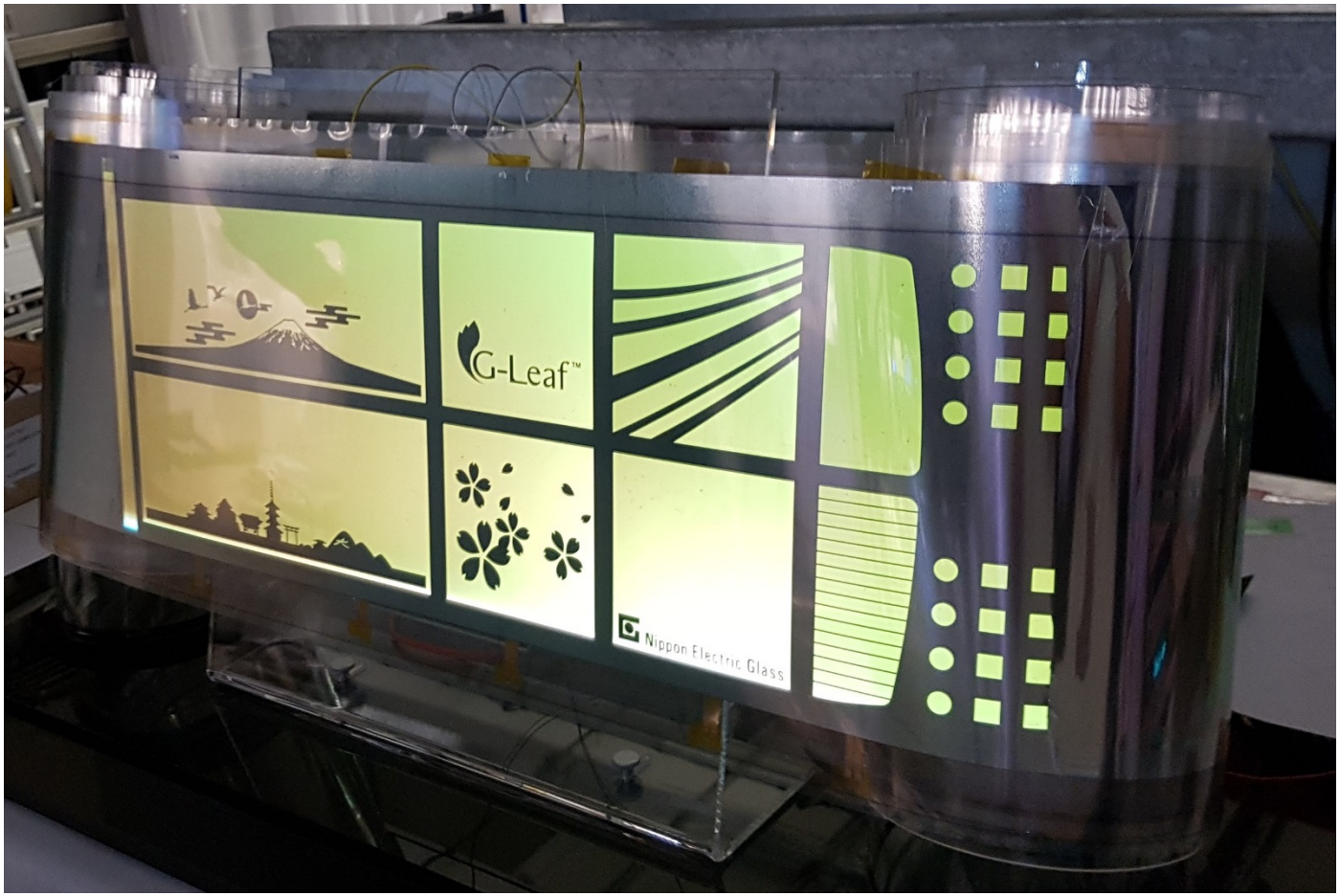
R2R OLED ON THIN GLASS ENCAPSULATED WITH THIN GLASS (50 µM)



A successful demonstration of 25 x 10 cm² OLED devices without dark spot growth!

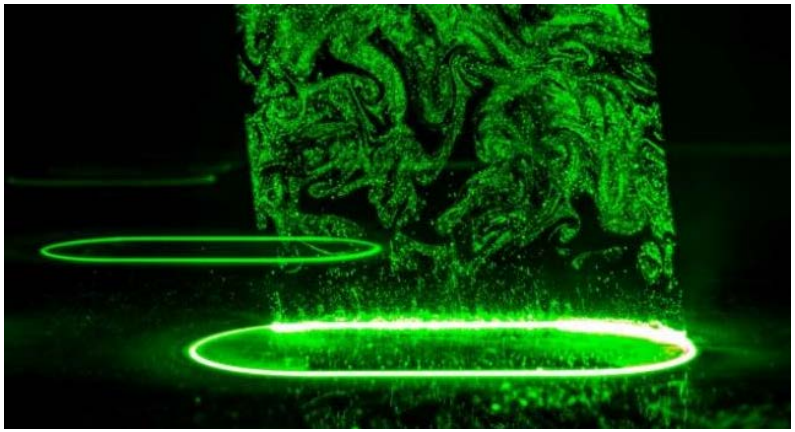
Development of proper cutting technology!

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

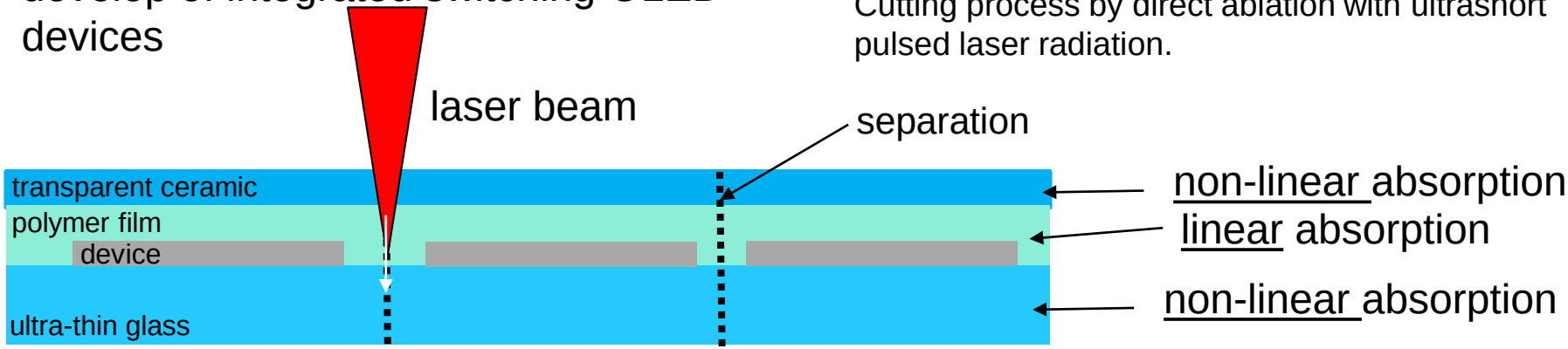
FRAUNHOFER CEGLAFLEX PROJECT: FLEXIBLE OLED DEVICES ON ULTRA-THIN GLASS CERAMIC LAMINATES

Goal of the project:

- transparent ceramics for scratch protection and OLED devices on ultra-thin glass laminates.
- laser cutting and polishing of transparent ceramics and ultra-thin glass device compounds achieving high edge stabilities.
- develop of integrated switching OLED devices



Cutting process by direct ablation with ultrashort pulsed laser radiation.



The Fraunhofer project is implementing the complete process chain at five Fraunhofer Institutes: ILT (coordination), IPT, IKTS, FEP, IMWS

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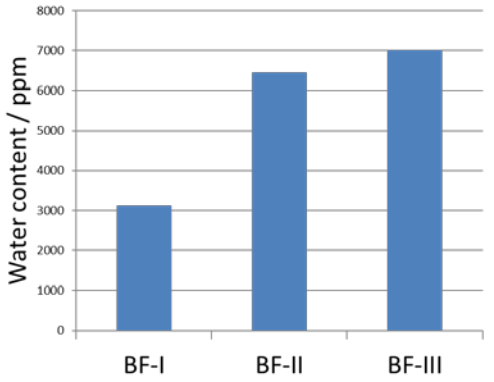
PLASTIC BARRIER FILMS ARE SMOOTH BUT INCLUDING MOISTURE

Residual water affects the OLEDs during manufacturing

- residual water on the surface, in the barrier and electrode films -> direct influence
- residual water in the PET film -> indirect influence (backside in front of top side)
- R2R drying process for several substrates developed
- proper storage/transport of rolls required



Barrier film not dried before OLED process.

Barrier film dried for 10 min. at 100 °C under N2 condition before OLED process

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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
- vacuum based OLED deposition
- Roll-to-Roll OLED fabrication process
- Material evaluation from laboratory scale to R2R production, with significant yield statistic.

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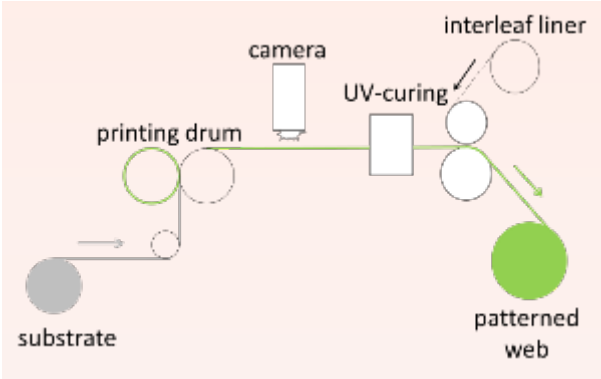
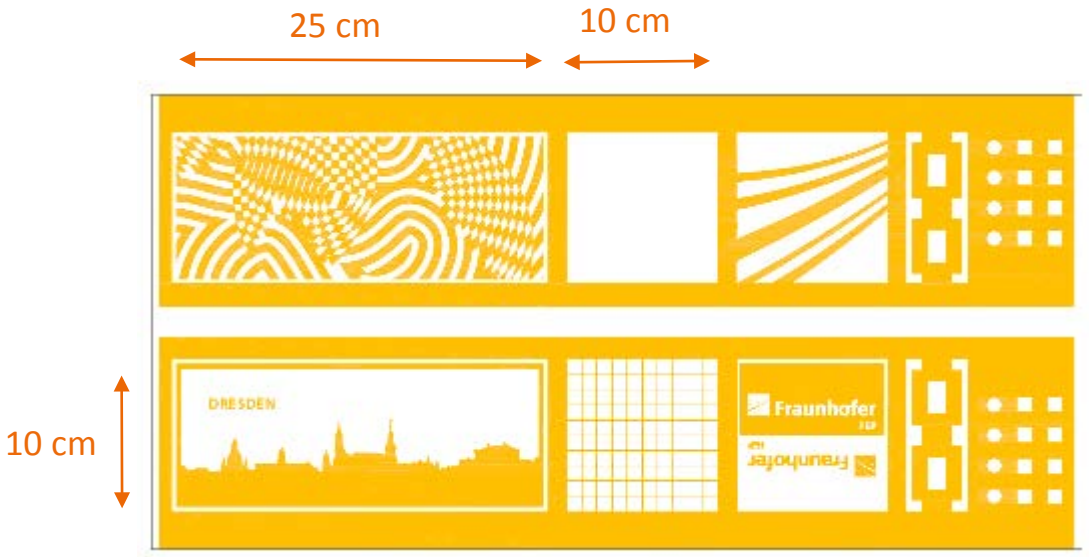
R2R OLED LAYOUT

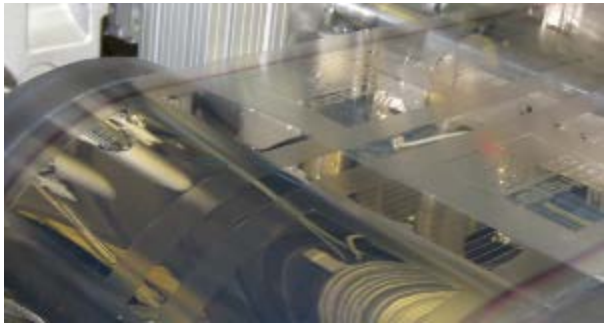
- Substrate structuring by printing
- Any kind of **customer specific** active OLED lighting areas are possible.
- Additional metallization printing for interconnection will be available soon.





Total layout length 300 x 628 mm.

Printing concept (up) and substrate after structuring (down)



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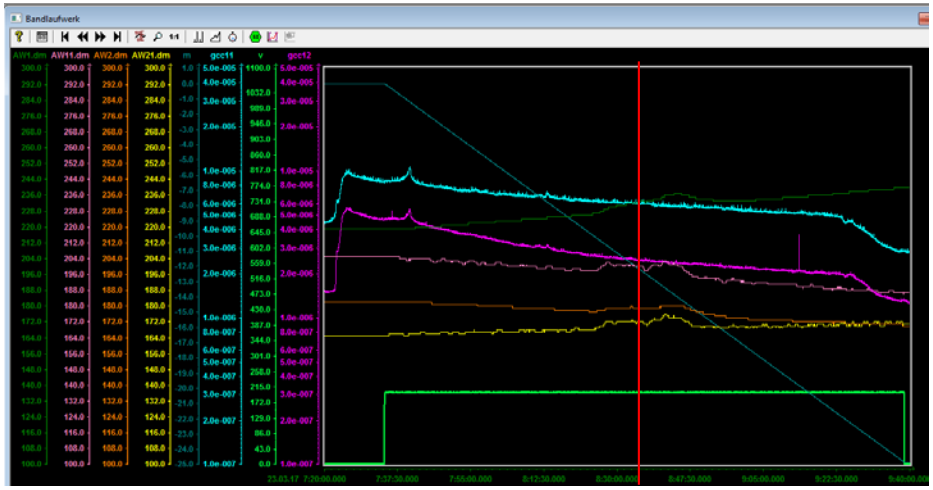
BENEFIT OF ROLL-TO-ROLL OLED MANUFACTURING

- It is possible to realize cost effective long OLED stripes or large OLED area.
- Fast response for customer-specific printing technology for substrate patterning and more...
- Higher amount of devices, because of higher throughput.
  - Manufacturing of 500 OLED devices in a size of 10 x 10 cm² per day is already possible under “R&D condition”.
- Possible lower clean room class is needed.
- First focus: Design driven ambient- and decorative OLED applications.

KNOWLEDGE MANAGEMENT FOR IMPROVEMENT PROCESS STABILITY



process parameter control over time

@ 1000 cd/m²

U [V]	CE [cd/A]	PE [lm/W]	CIEx	CIEy
3.54	53.2	47.3	0.464	0.525

Corresponding OLED key values on rigid glass fabricated in the cluster tool.

OLED key values

Shortcut	Waferlabel	V1000 [V]	J1000 [mA/cm²]	CE1000 [cd/A]	PE1000 [lm/W]	CIEx1000	CIEy1000
4	A	3,89	2,3	43,2	35,0	0,464	0,530
4	B	3,84	2,3	44,2	36,3	0,453	0,541
7	A	3,72	2,3	43,5	36,9	0,454	0,540
7	B	3,77	2,3	42,9	35,9	0,444	0,549
11	A	3,61	2,2	45,9	40,1	0,450	0,543
11	B	3,58	2,2	45,7	40,2	0,440	0,553
15	A	3,59	4,5	21,5	18,7	0,450	0,543
15	B	3,57	2,1	47,9	42,3	0,441	0,552
17	A	3,55	2,2	46,5	41,3	0,450	0,543
17	B	3,52	2,1	47,0	42,0	0,441	0,552
21	A	3,49	2,1	46,8	42,1	0,447	0,546
21	B	3,47	2,7	36,8	33,1	0,445	0,548
22	A	3,51	2,2	45,8	41,0	0,449	0,545
22	B	3,49	2,1	47,2	42,5	0,450	0,544

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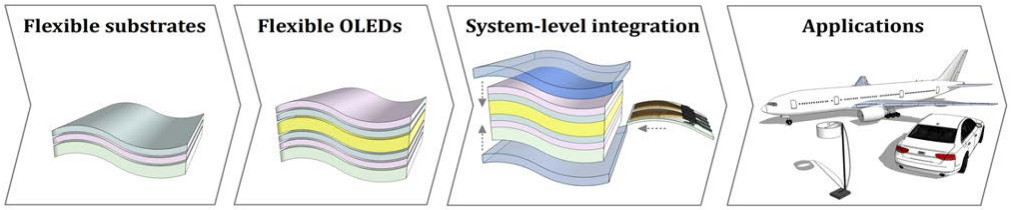
Consortium & Capabilities

PI-SCALE
SHAPING THE FUTURE IN OLED LIGHTING

The pilot line includes all the steps required to create advanced flexible OLED product prototypes:

- High performance **moisture barrier** and **electrode films**
- **Flexible OLED fabrication** in sheet-to-sheet and roll-to-roll process
- Flexible device **encapsulation**
- **Lamination**, **bonding** and **system-level hybrid integration** of thin film flexible electronics



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Open Innovation by imec and TNO
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FlexEnable
Truly flexible electronics

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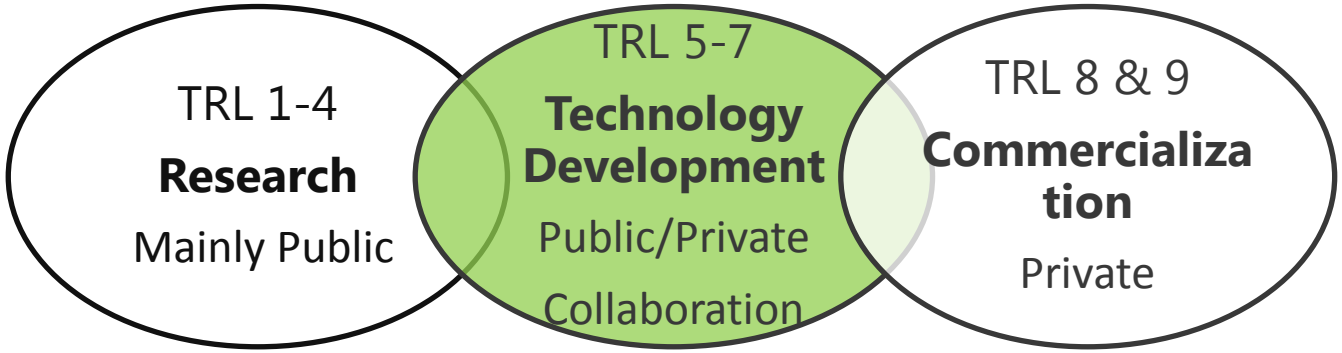
This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 688093



PI-SCALE

The PI-SCALE pilot line service fills that gap and helps to translate your ideas into products

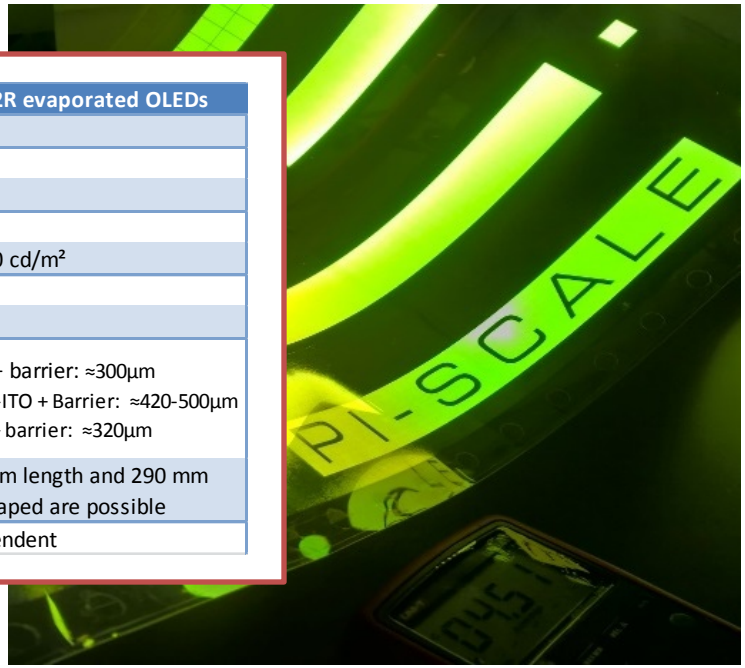
This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 688093

R2R OLEDs

R2R evaporated OLED

- **300mm** web-width, up
  length
- **Good performance** O
- **Customised** OLED **sh**
  possible
- **Large form factor** OL

Parameter	PI-SCALE R2R evaporated OLEDs
Color	yellow
Luminance efficacy	30 lm/W
Operational lifetime	> 500h
Shelf lifetime	n.a.
Operating current voltage @ luminar	4-5V @1000 cd/m²
Luminance	1000 cd/m²
CIEx/y	0,490/0,504
Thickness	thin-glass + barrier: ≈300µm Barrier+ PET-ITO + Barrier: ≈420-500µm Barrier-ITO + barrier: ≈320µm
Shape	up to 600 mm length and 290 mm width all shaped are possible
Area	design dependent



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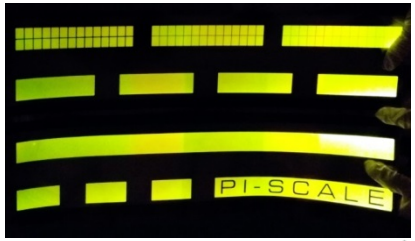
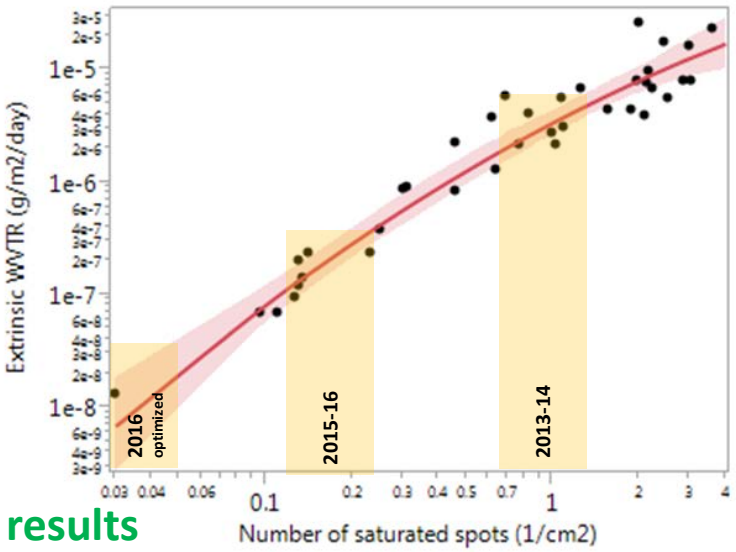
R2R Flexible Barrier Film – current status

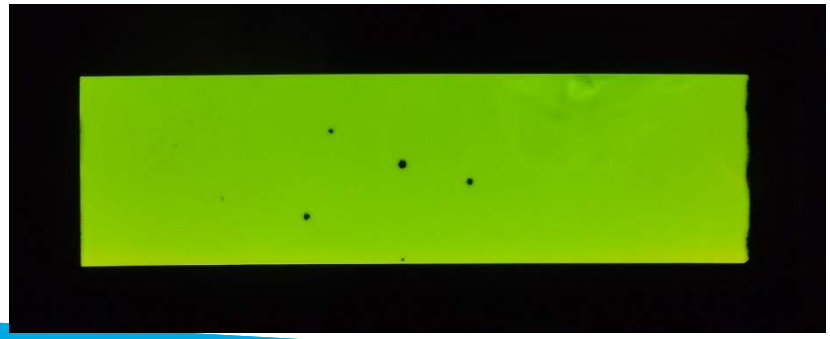
- Pinhole density = excellent measure for barrier properties
- Standard R2R single SiNx barrier; iWVTR < 2.10^{-6} g/m²/day
  - **eWVTR ~ 2.10^{-7} g/m²/day; 0.13 pinholes/cm²**
- Improved R2R single SiNx barrier
  - **eWVTR~ 1.10^{-8} g/m²/day; 0.03 pinholes/cm²**

OLED quality R2R produced Barrier





Pinhole results in black spots



High quality level for barrier film manufacturing needed!

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 688093

R2R OLEDs
Ideal for low price and quantity

R2R Evaporated OLED	Bottom barrier	Anode & Structuring	OLED & Cathode	Encapsulation		Singulation	Characterization and testing	System integration
	HC R2R barrier, thin glass	ITO, ISO printing	OLED and Cathode evaporation	Lamination of HC R2R barrier		Roll slitting and cutting	Acc. shelf lifetime; Device el. characterization;	Component assembly, inj. molding ...

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 688093

OLED Features Available from 2018

Transparent OLEDs

Long strips >1m made by R2R

Active and passive matrix segmented OLEDs

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SUMMARY

- Flexible OLED lighting enable new functionalities and market entry for automotive lighting applications.
  - OLED does not replace LED, but complement each other perfectly
  - Unique characteristics of the OLED must be used consequently!
- The roll-to-roll OLED fabrication is feasible on metal-, plastic- and ultra-thin glass web for different kind of target applications.
- Comparable power efficacy between R2R and lab-scale OLED is possible.
  - Further reproducibility will be pushed within the EU PI-Scale project for S2S and R2R.
- Starting pilot production in Roll-to-Roll fabrication on barrier films and ultra-thin glass web coming soon feasible.
  - Remove residual moisture in coils has an impact on reproducibility.
  - Changes in the barrier film layer structure influences the winding behavior.

ACKNOWLEDGEMENT

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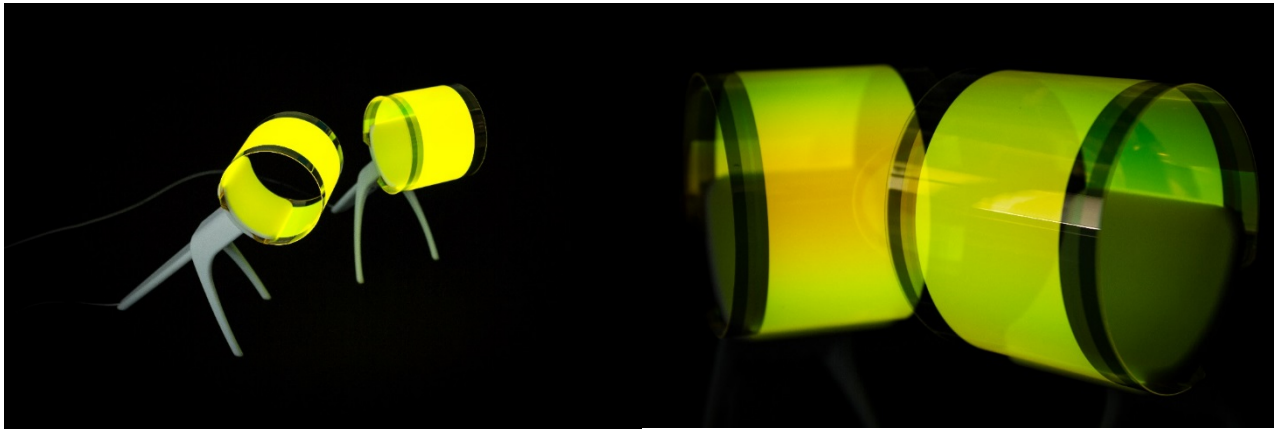

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