OLED MANUFACTURING CHALLENGES – SOME INPUT BY FRAUNHOFER FEP

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DOE Lighting R&D workshop

February 4, 2021

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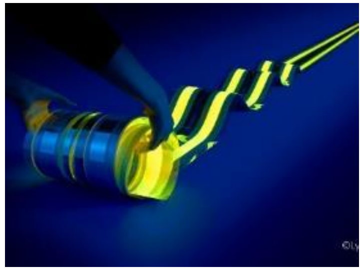
AGENDA

- Introduction: Fraunhofer FEP and OLED @ Fraunhofer FEP
- Flexible OLED: Segmented lighting strip for Automotive
- Segmentation: Freeform patterning
- Roll-to-Roll Manufacturing
- 3D direct deposition
- OLED project examples funded by the EC
- Summary and Acknowledgement



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FRAUNHOFER FEP: FACTS AND FIGURES

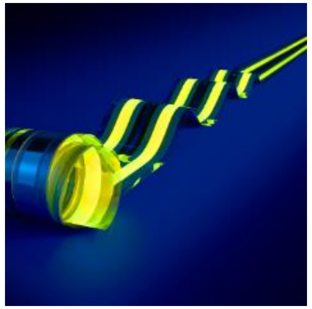
- Fraunhofer Institute for Organic Electronics, Electron Beam, Plasma Technology FEP - one of 74 institutes within Fraunhofer Gesellschaft, Europe’s largest application-oriented research organization

- Director: Prof. Dr. Volker Kirchhoff
- Figures 2019: employees 178, total budget 25.0 M€, industry returns 9.9 M€, public funding 7.4 M€, investments 2.0 M€

- Core competences:

ELECTRON BEAM TECHNOLOGIES

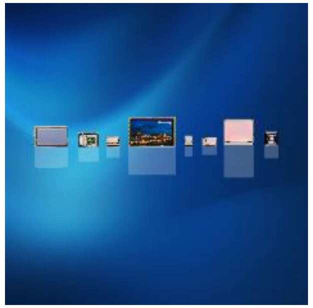
PLASMA-ACTIVATED COATING



ORGANIC ELECTRONICS

ROLL-TO-ROLL TECHNOLOGY

TECHNOLOGICAL KEY COMPONENTS

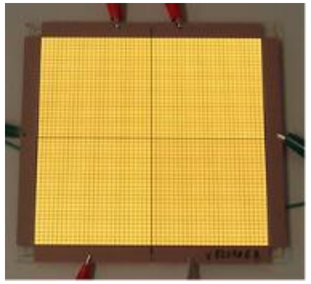


IC DESIGN

OLED LIGHTING @ FEP

Focus on unique features of the OLED

2008



Rigid glass

150 x150 mm² panel

8.7 lm/W

2011

Rigid glass

330 x 330 mm² panel

27 lm/W

2012

rigid glass, segmented

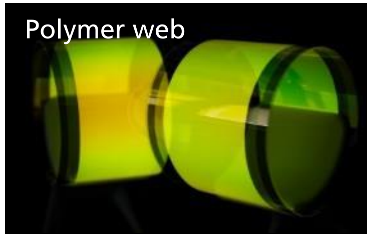
1st tail light prototype

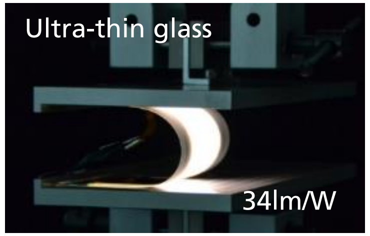
(with Hella)

2013/14

Transparent, Color-tunable OLED

2016/17

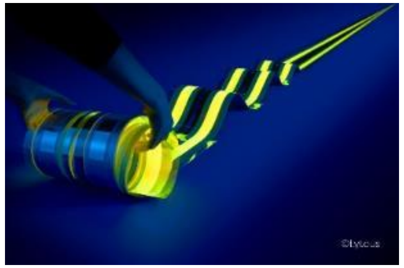




Polymer web / ultra-thin glass

58mmx175mm panel

2018



OLED stripe - 15 m R2R

Future

Segmented, Animated Light

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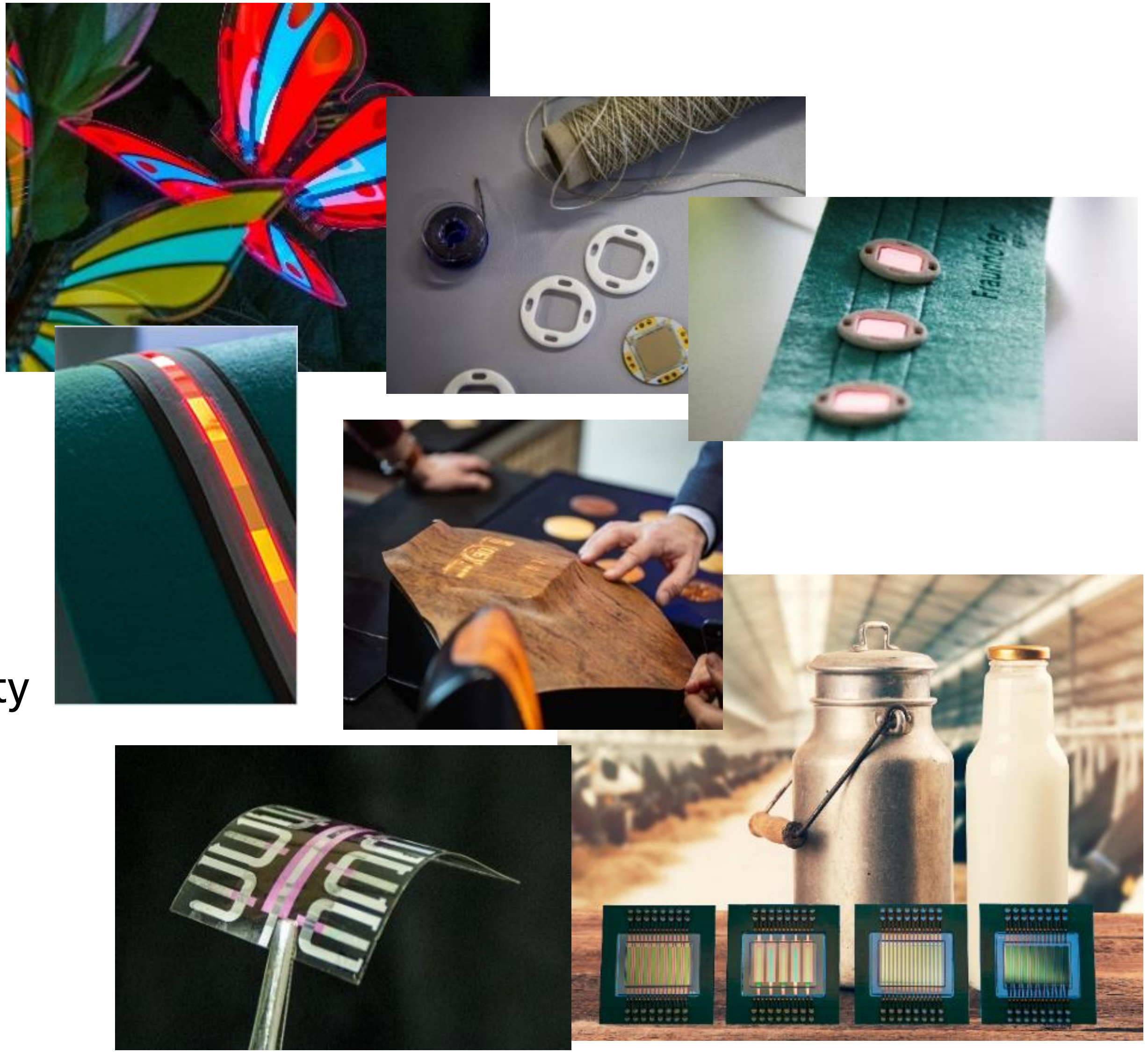
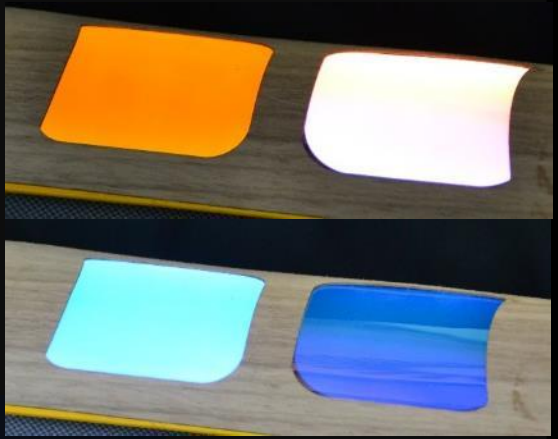
OLED AND MORE - SOME LATEST RESEARCH RESULTS

- OLED
  - MONARCH - OLED Lighting Design Sample Kit
  - Wearables/Textile integration
  - Modular light stripes
  - Integration in wood
- OPD
  - Sensor for rapid test to ensure high milk quality
- Photovoltaics
  - Vacuum deposited perovskite layers
- Biodegradable electronics
  - Flexible biodegradable transistors



FLEXIBLE OLED: VISIONS FOR AUTOMOTIVE

transparent OLEDs, red + amber



color tunable OLED

twisted OLED

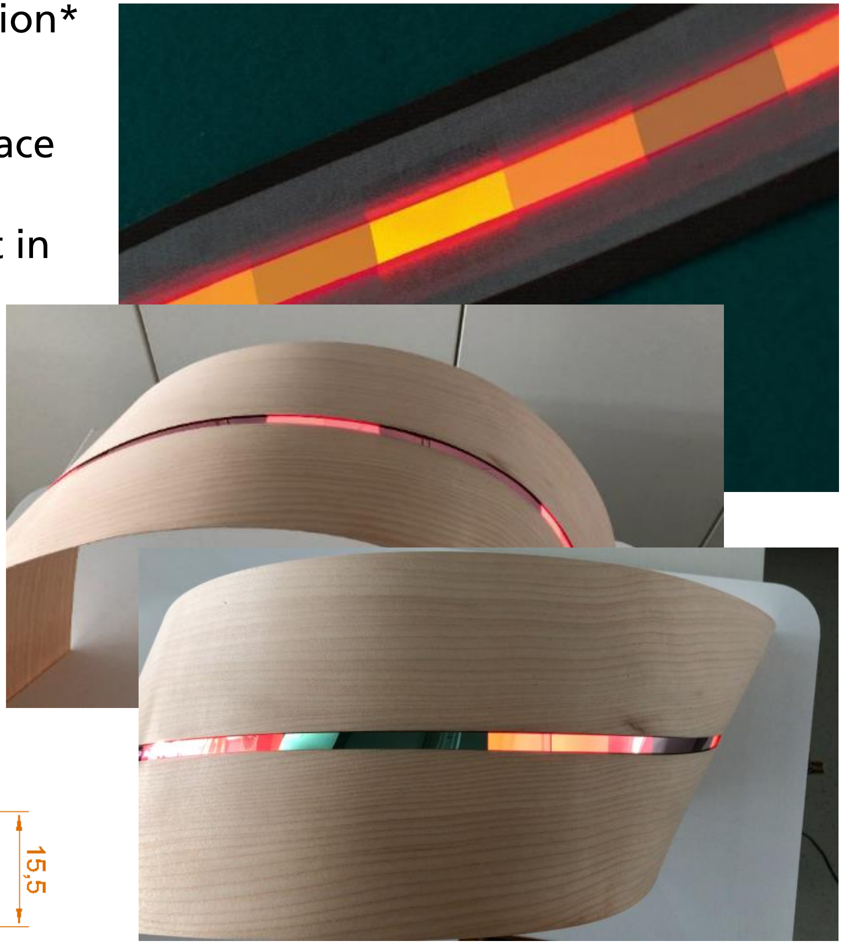
50 cm toy car

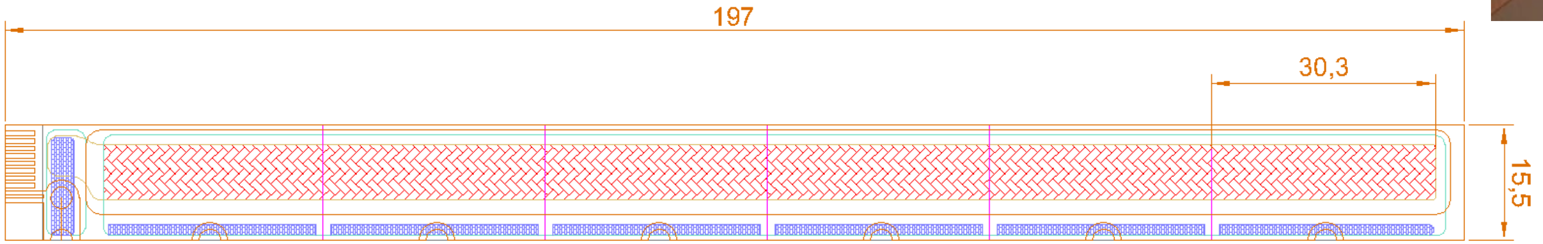
transparent OLED
logo behind

APPLICATION EXAMPLE:
INFINITE SEGMENTED LIGHTING STRIP FOR AUTOMOTIVE

- Most important OLED feature employed in automobile taillights is segmentation*
- Even more attractive: bended or transparent emissive area
- OLED strip demonstrator - can be tiled and behave like a single luminous surface without interruption
  - Any number of OLED modules can be connected - lined up modules result in quasi endless long segmented strips
  - Individual segments can be controlled separately (6 addressable segments per module) => Dynamic control or dimming opens up additional possibilities, such as for welcoming scenarios or dynamic warnings
  - Flexible (< 300 µm thick); can be transparent

No satisfying high-brightness solution available by inorganic LED - use of OLED makes it possible to avoid "pearl chain effect" (LED light points due to insufficient light scattering)





* https://www.audi-mediacenter.com/en/press-releases/brand-with-the-four-rings-shines-at-worlds-largest-lighting-congress-12008

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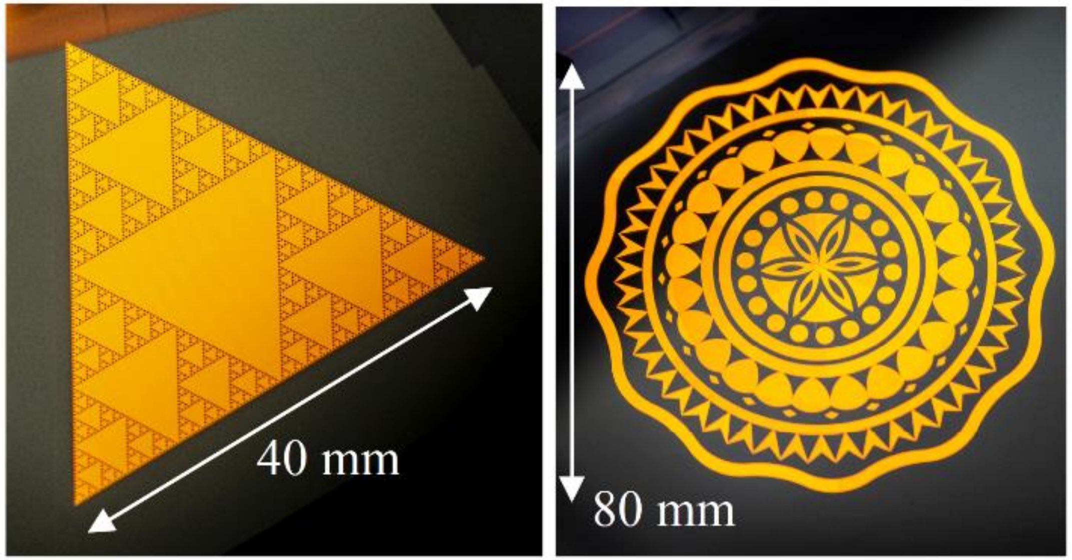
SEGMENTATION: FREEFORM PATTERNING

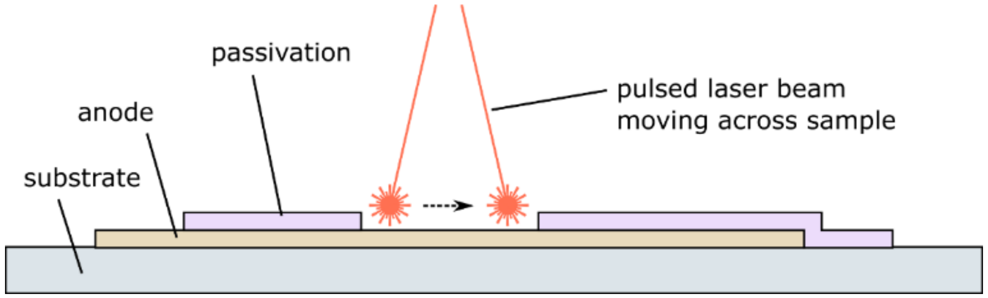
- Standard: combination of electrode segmentation and shadow masking
  - No complete freedom of design, mechanical restrictions, e.g. layout not containing islands
- Novel technology:
  - Coating a passivating layer on top of bottom electrode
  - Patterning via laser ablation
    → complete control over the emission area
  - down to feature sizes of about 30 µm
  - OLED to light up only in the previously laser irradiated area.
  - Passivation material itself is not fixed and can be matched to specific demands of the OLED process

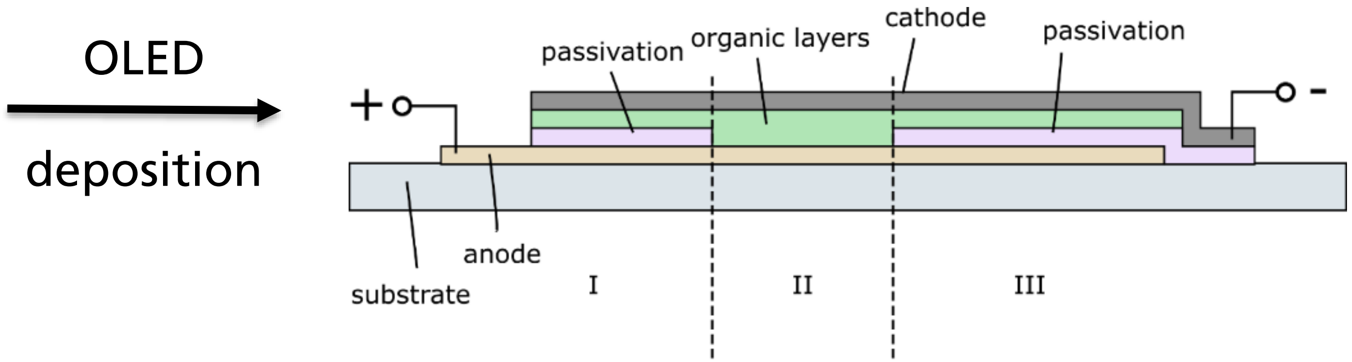


OLEDs patterned by coating and subsequent partial laser ablation of passivation layer

Both designs would be impossible by just using shadow masks for patterning

FREEFORM PATTERNING VIA LASER ABLATION OF PASSIVATION LAYER





- Pretreatment
  - Substrate: ITO glass
  - Deposition of passivation
    - Full area deposition layer (here: TiO_x, can also be ceramic, organic polymer, other metal oxide, …)
    - Selective removal via laser

→ Patterned electrical insulation

- OLED
  - Region II emits light, while I and III stay dark
  - Patterned emission without shadow mask
  - Independent of color / stack
  - Opaque and transparent devices possible

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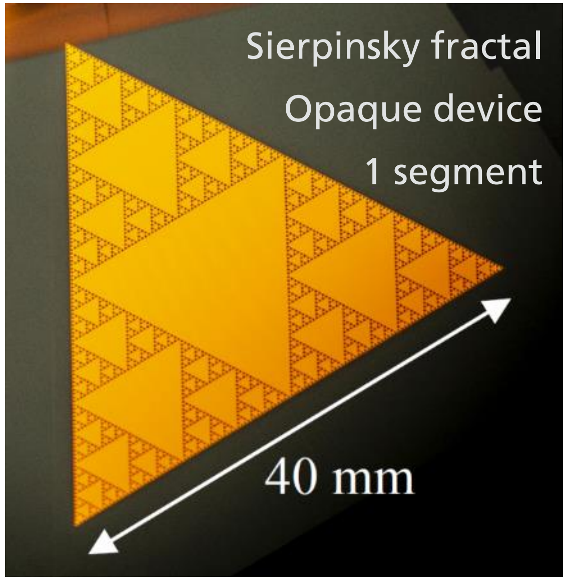
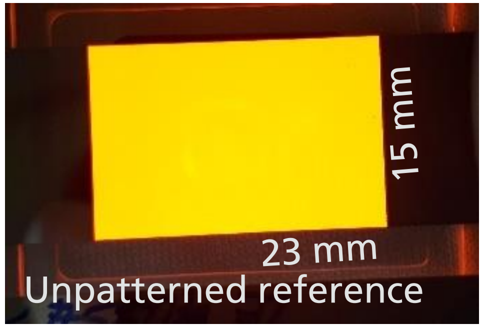
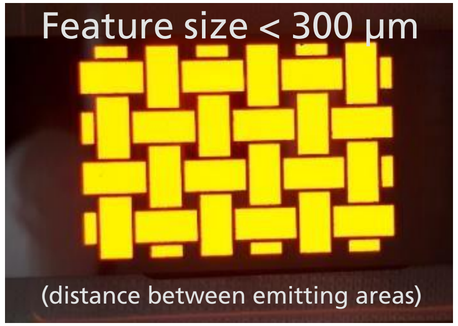
POSSIBILITIES OF FREEFORM PATTERNING

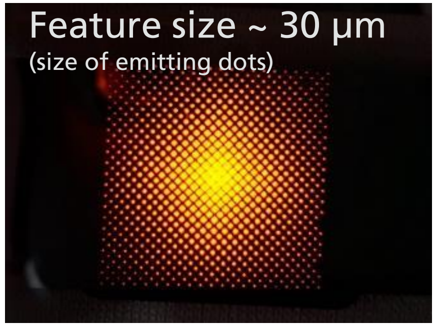
- Contact free → substrate protection
- No mechanical necessities like bridges in shadow mask
  - complete freedom of design
- Digital process
  - No cost / lost time in case of layout update
  - Laser scanning speed of about 1 m/s => complex pattern in a device of 100 cm² area can be realized in minutes

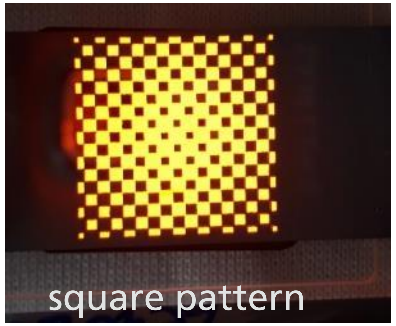


- Patterned devices in 23×15 mm²:



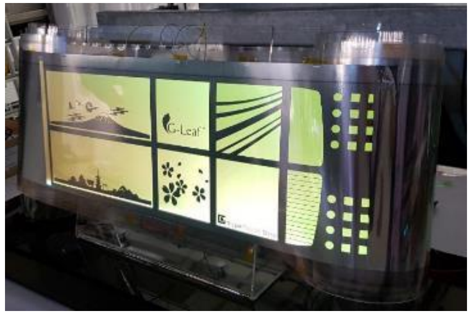






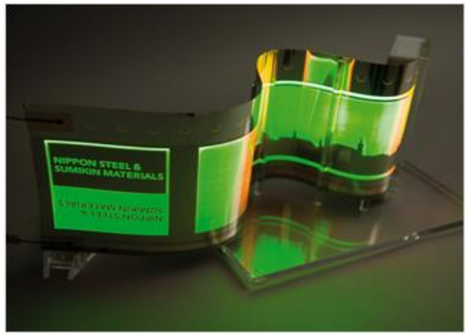
ROLL-TO-ROLL MANUFACTURING

- Use of flexible substrates is not only an advantage in terms of design aspects
- Moreover, flexible substrates enable roll-to-roll deposition technology for OLED manufacturing
- Roll-to-roll processing, in turn, enables new designs
- R2R enables 15 % less production costs in comparision to S2S*
  (assumptions: capacity 700 km²/a; 80 % usage, 90 % yield); e.g.:
    - R2R throughput +15 % (no gaps between substrates)
    - R2R material cost -15 % (higher utilization, no gaps between substrates)
    - R2R uptime -5% (coil change)
    - R2R substrate cost -20 % (no carrier required)
    - R2R substrate usage +5% (“infinite” in transport direction)
- OLED R2R current research
  - Further improvement in handling of ultra thin flexible glass
  - Transparent top electrode
  - Patterning and segmentation



Ultra-thin glass

Polymer webs



Metal strips

* Source: N. Riegel, R2D2 project report, 2016

ROLL-TO-ROLL OLED FABRICATION AT FRAUNHOFER FEP

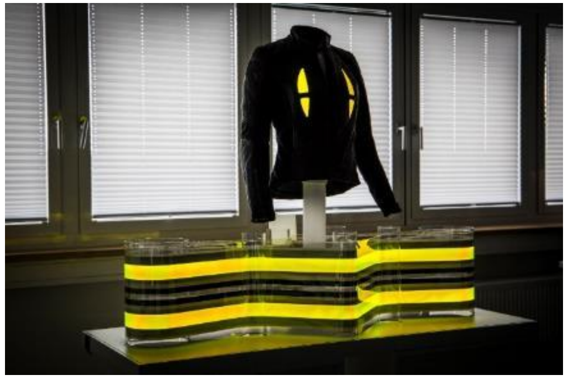

R2R inspection system


R2R printing and lamination unit (N_2)


R2R vacuum coater

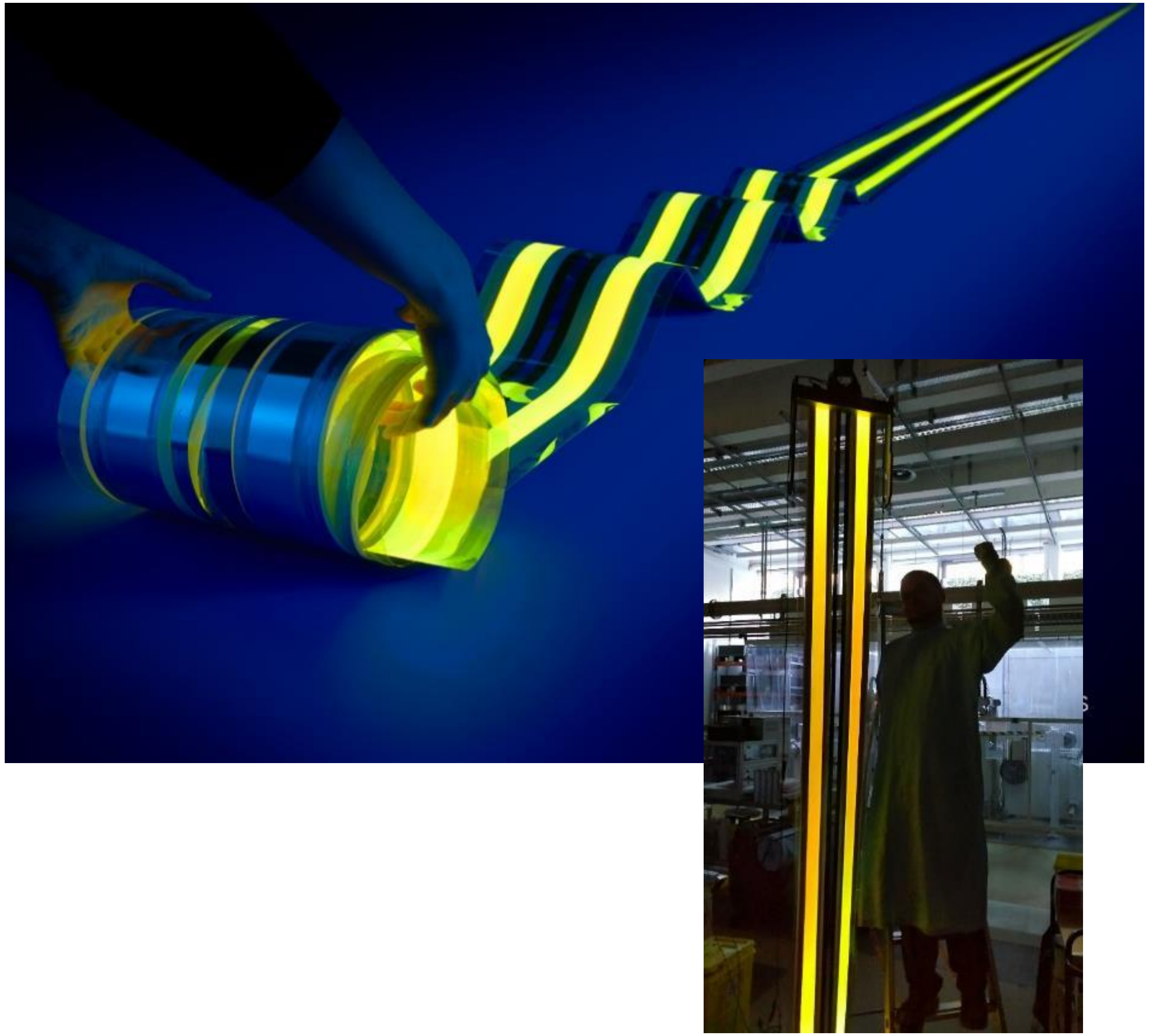
Substrate Inspection → Structuring → Substrate inspection → Vacuum coating → Encapsulation → OLED characterisation

- Typically 300 mm web width
- metal strip: thickness up to 500 µm
- polymer web: thickness 50 to 500 µm
- flexible glass: thickness 50 and 100 µm preferably - “pure” or laminated on PET



15-METER ROLL-TO-ROLL DEVICE - WORLD'S LONGEST OLED

- Hybrid device made by Fraunhofer FEP and Holst Centre within EC project Pi-scale
- Process steps:
  - Holst: R2R Barrier deposition
  - FEP: R2R ITO anode deposition
  - Holst: R2R slot-die coating to structure the anode and deposit the first layer of the OLED stack
  - FEP: R2R OLED stack evaporation
  - FEP: R2R lamination of Holst Centre barrier
- Combines the performance of an evaporated OLED stack with solution processed layers

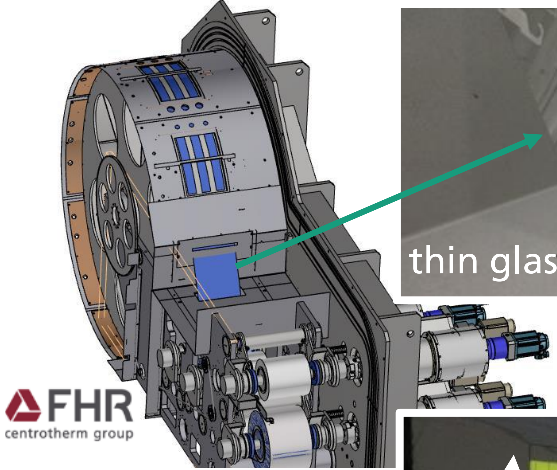


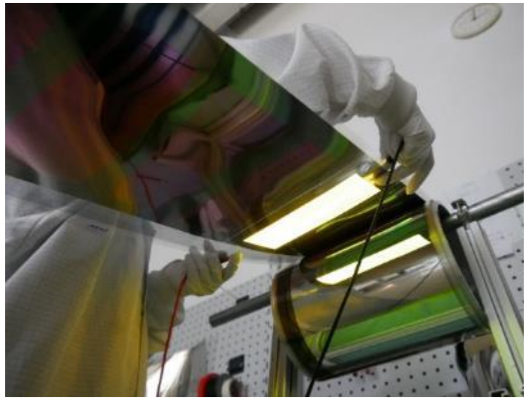
PI-SCALE
Fraunhofer FEP

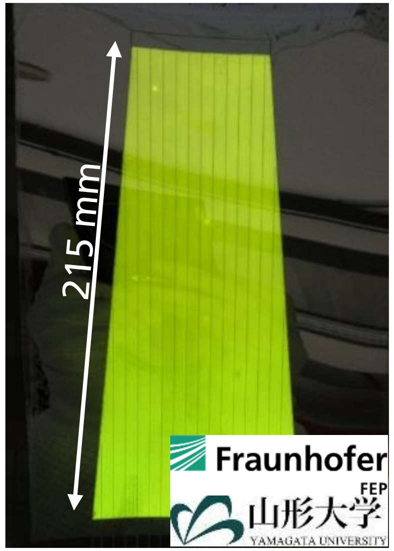
ULTRA-THIN GLASS WINDING FOR R2R OLED

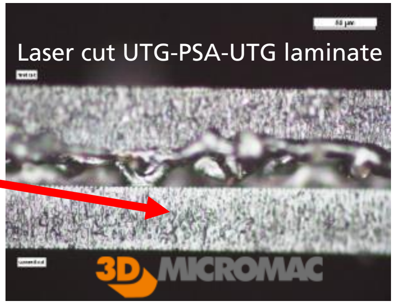
- Project LAOLA - Large area OLED lighting applications on ultra-thin flexible substrates - German partners funded within BMBF funding measure "Internationalisation of Leading-Edge Clusters …"
- Main topics
  - winding processes to be integrated into the vacuum coating system – system upgrade done by FHR and FEP
    - web tension: 30 N – 500 N
    - speed: 0.2 …0.8 m/min
  - laser cutting for module separation; R2R structuring processes by screen printing
- Challenges
  - yield (glass handling between process systems)
  - material cost

German partners	Japanese partners
• OES - Organic Electronics Saxony (management) • Fraunhofer FEP (OLED technology R2R) • FHR Anlagenbau (winding) • 3D-Micromac (Laser cutting) • WOLFRAM Design/Engineering (demonstration) • tesa (adhesive) • further: CREAVAC, Heliatek, CreaPhys	• Yamagata University (R2R screen printing) • NEG (G-Leaf) • Fujikura Kasei (ink) • Seria (R2R screen printing systems) • MDI (cutting) • NSCM Nippon Steel Chemical & Material



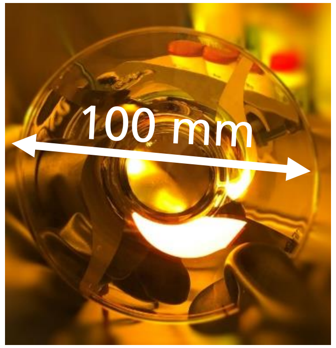






OUTLOOK:
OLED BY DIRECT VACUUM DEPOSITION ON 3D SHAPED SUBSTRATES

- Substrate: an ordinary glass teacup saucer
- Vacuum deposition of ITO anode
- Laser patterning of ITO anode
- Vacuum deposition out from point sources
  - using 3D printed shadow mask*
  - standard stack (orange, 3V, 10mA)
- Encapsulation by ALD and lacquer
- Next steps:
  - Upscaling/industrialization
    - adapted equipment
    - yield and lifetime issues



*patent pending

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O.Light - OLED & HUMAN CENTRIC LIGHTING supported by SmartEEs

- SmartEEs prototype: Human-centric light by LED/OLED combination – proposal by ESYST
  - Aesthetically pleasing smart lights
  - LED emission and light quality (color temperature) expanded by
    - tuneable-white and amber OLEDs (two units each)
- Services by Fraunhofer FEP:
  - Customer specific transparent color-tunable OLED modules
- Services by AMIRES:
  - Business case, market segments, competitor and partner analysis

- SmartEEs - European acceleration program dedicated to supporting SMEs and Mid-caps in integrating flexible and wearable electronics into novel products / series of products https://smartees.eu/
- SmartEEs offer*
  - Innovative Company (end-users):
    - up to 100 k€ support for your idea
  - Technology suppliers:
    - up to 60 k€ voucher for services
  - Brokering
  - Value chains building
- Call for Application Experiments: deadlines 07/05/2021 and 31/08/2021

https://youtu.be/uRA0wADXL_o

This project has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement No. 761496 and 872076.

*within Europe only

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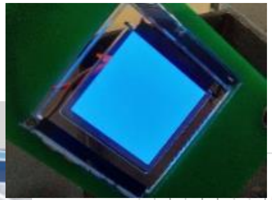
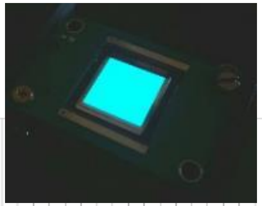
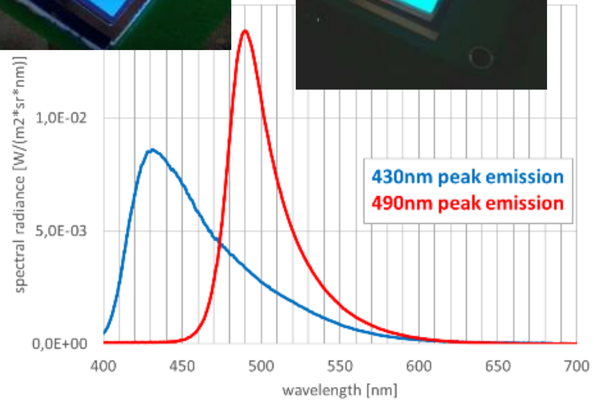
Customized OLED for PoC instruments supported by ACTPHAST4.0

- Innovation project with OR-EL Organska Elektronika d.o.o.: development, preparation and manufacturing of customer specific larger area OLED light sources for a POCOrel Point-of-Care (PoC) instrument based on immunofluorescence
- Services by Fraunhofer FEP:
  - Customer specific OLED layout
  - OLED stack adjustment for 430 nm and 490 nm emission
  - Manufacturing of several hundred OLED modules for the OR-EL PoC instrument







- ACTPHAST: unique one-stop-shop open access full supply chain for supporting photonics innovation*
  - integrating more than 200 top-experts from 25 institutes to accelerate the business of European SMEs to industry
- ACTPHAST4.0: specially designed to support European SME's who want to boost the innovation of their projects with photonics
  - European SMEs may receive a subsidy of 75%-100% of their innovation project (100% subsidy for the first 30 k€ of project costs and 75% subsidy for costs above 30 k€)
  - large-scale European companies receive a 50% subsidy
- ACTPHAST4R: aims to support researchers who have a conceptional breakthrough and would like to realize their early stage demonstrator with mature photonics technologies
- Registration of interest and further information: https://www.actphast.eu/

ACTPHAST4.0 is an Innovation Action funded by the European Commission under H2020 Grant Agreement N° 779472.

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SUMMARY

- Fraunhofer FEP as the R&D partner to industrialize OLED lighting
- Flexible OLED: segmented lighting strip for automotive - - without "pearl chain effect”
- Freeform patterning via laser ablation of passivation layer enables unique designs – module individualization in mass production
- Main challenge: Cost
  - R2R manufacturing can bring cost down at high throughput and can enable R2R unique designs, ultrathin glass as highly attractive substrate
- 3D direct deposition as promising approach for OLED integration in multi-curved surfaces
- OLED industrialization examples - thanks to attractive European funding schemes

- Acknowledgement
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  - Activities have received funding from the European Union’s Horizon 2020 research and innovation program under grant agreement No. 688093 (PI-SCALE), 761496 (SmartEEs) and 779476 (ACTPHAST).
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