OLED LIGHTING TECHNOLOGY AND ITS APPLICATION

Dr. André Philipp, Fraunhofer FEP

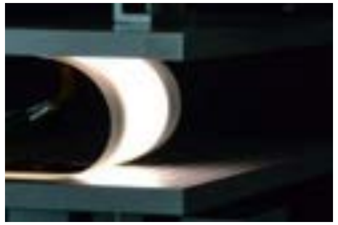
SmartEEs Workshop – Flexible and Wearable Electronics

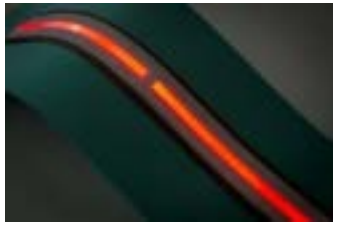
02.06.2021

AGENDA

- OLED Basics
  - OLED History
  - OLED technology overview
  - Flexible OLED lighting

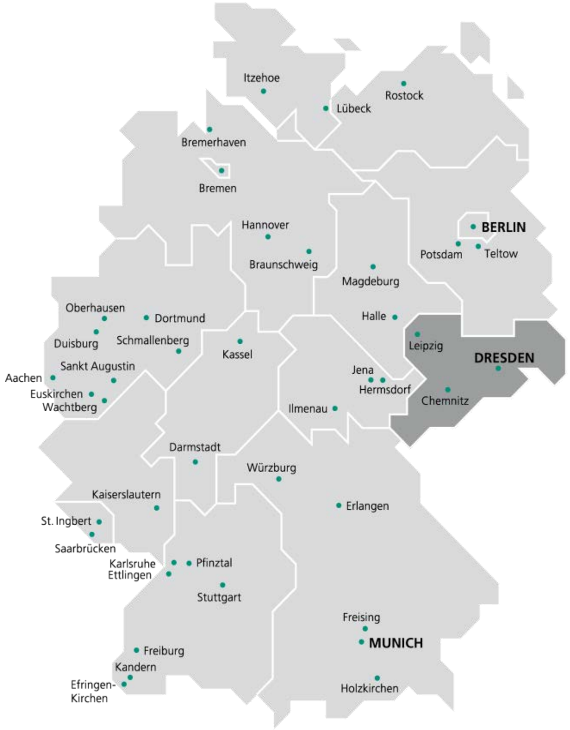
- OLED lighting for different applications
  - Automotive
  - Textile
  - Logos and Letters
  - 3D
  - Color-tuneable





Fraunhofer FEP

FRAUNHOFER FEP – FACTS AND FIGURES



- Fraunhofer Institute for Organic Electronics, Electron Beam, Plasma Technology FEP - one of 75 institutes within Fraunhofer Gesellschaft, Europe’s largest application-oriented research organization

- Director: Prof. Dr. Elizabeth von Hauff, Prof. Dr. Volker Kirchhoff
- Figures 2020: employees 182, total budget 25.6 M€, industry returns 9.3 M€, public funding 10.5 M€, investments 1.4 M€

- Core competences:

ELECTRON BEAM TECHNOLOGIES

PLASMA-ACTIVATED COATING

ORGANIC ELECTRONICS

ROLL-TO-ROLL TECHNOLOGY

TECHNOLOGICAL KEY COMPONENTS

IC DESIGN

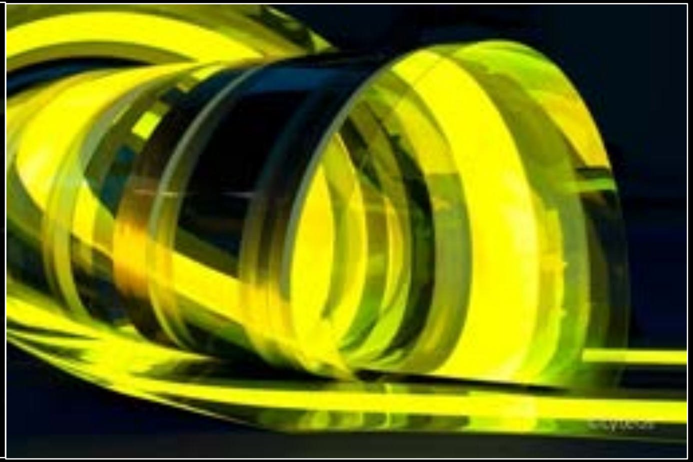
Fraunhofer FEP

WHY OLED LIGHTING?


Thin & Light


Variety of forms


Transparency

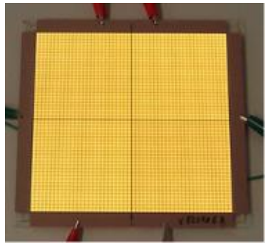

Flexibility

Modules by Fraunhofer FEP

OLED LIGHTING TECHNOLOGY – FRAUNHOFER FEP

Focus on unique features of OLEDs

2008



Rigid glass

150 x150 mm² panel

8.7 lm/W

2011

Rigid glass

330 x 330 mm² panel

27 lm/W

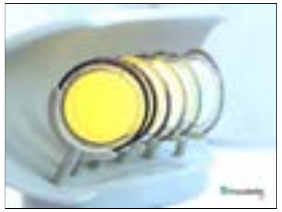
2012

rigid glass, segmented

1st tail light prototype

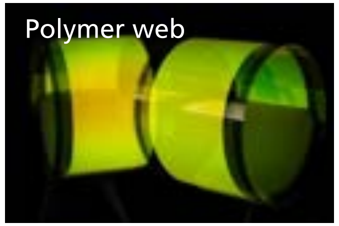
(with Hella)

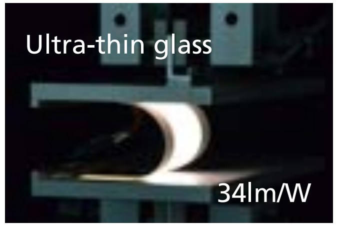
2013/14



Transparent, color-tunable OLED

2016/17





Polymer web / ultra-thin glass

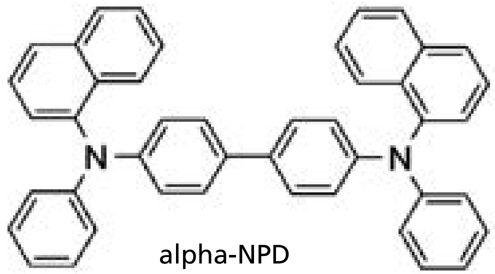
58 x 175 mm² panel

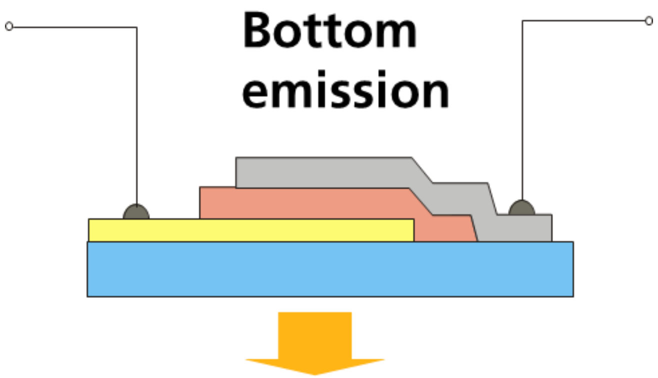
Future

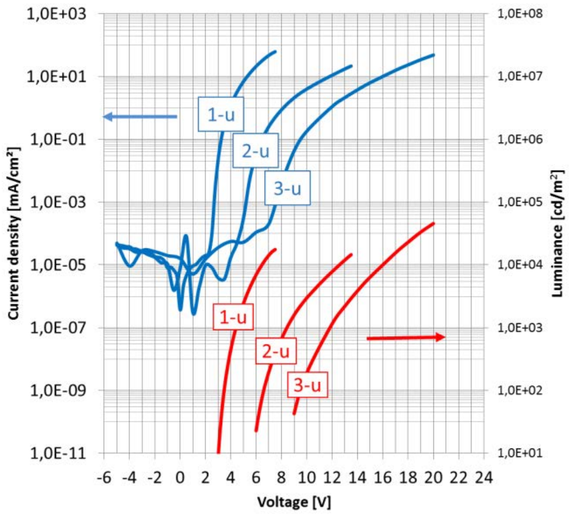
Segmented, animated Light

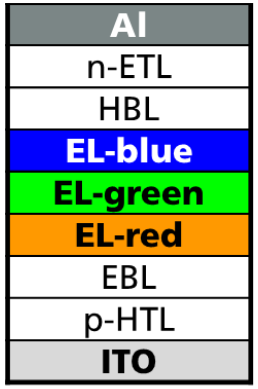
Fraunhofer FEP

OLED BASICS





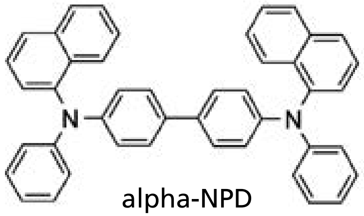




1-unit

Fraunhofer FEP

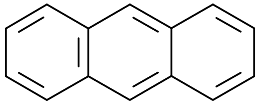
OLED HISTORY AND ORGANIC MATERIAL



alpha-NPD

C60

- History and Potential
  - 1906 photo conductivity observed for Anthracene
  - 1964 electro-luminescence observed for Anthracene



Anthracene

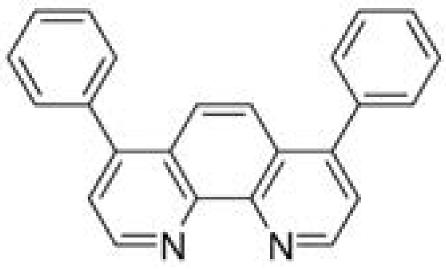
  - 1977 highly cond. polymer materials (Heeger, Nobel prize 2000)
  - **1986 1st org. solar cell (Tang et al.)**
  - **1987 1st OLED (Tang et al.)**
  - 2002 1st commercial OLED-Displays
  - 2009 1st commercial OLED for lighting (OSRAM)

- Organic
  - organic compound as defined by chemistry
  - carbon containing compounds with some exceptions (e.g. CO, CO_2, H_2CO_3, carbonates, carbides)
  - here: all synthetic, not „biological“
- Semiconductor
  - el. resistance lower than resistance of insulators but higher than that of conductors
  - conducting properties may be altered by introduction of impurities
  - charge carrier concentration increases with temperature
- Of practical relevance
  - organic materials with extended pi-electron systems

Fraunhofer FEP

OLED – ORGANIC MATERIAL CLASSES

Small Molecules

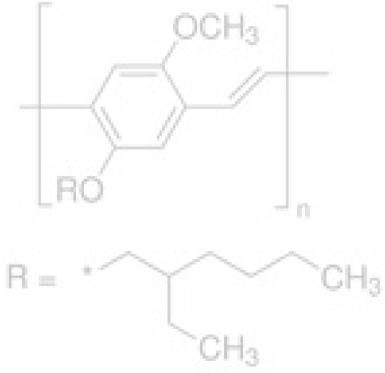


BPhen

- Molar mass: < 1.000 g/mol[1]
- Advantages:
  - high-purity materials (sublimation)
  - suitable for complex layer stacks

  ➔ high-efficiency OLEDs
- Challenges:
  - thermal evaporation under ultra high vacuum

Polymers



MEH-PPV

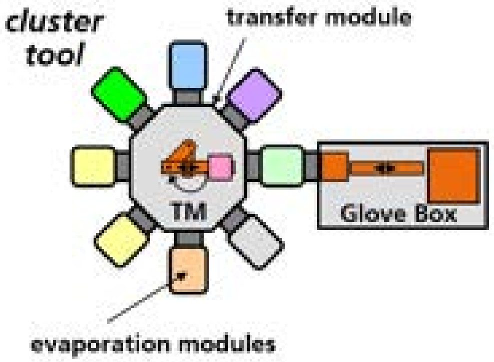
- Molar mass: > 10.000 g/mol[1]
- Advantages:
  - Liquid phase using various printing and spin coating processes
- Challenges:
  - thermal evaporation under ultra high vacuum
  - poorly suited for complex layer stacks

[1] J. Lee, D. Liu, and S. Wu, *Introduction to Flat Panel Displays*, ser. Wiley Series in Display Technology. Wiley, 2008.

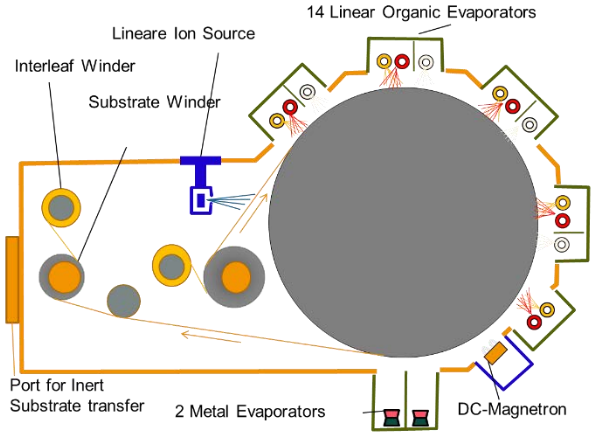
Fraunhofer FEP

OLED LIGHTING TECHNOLOGY – MANUFACTURING TECHNOLOGY

200mm S2S System



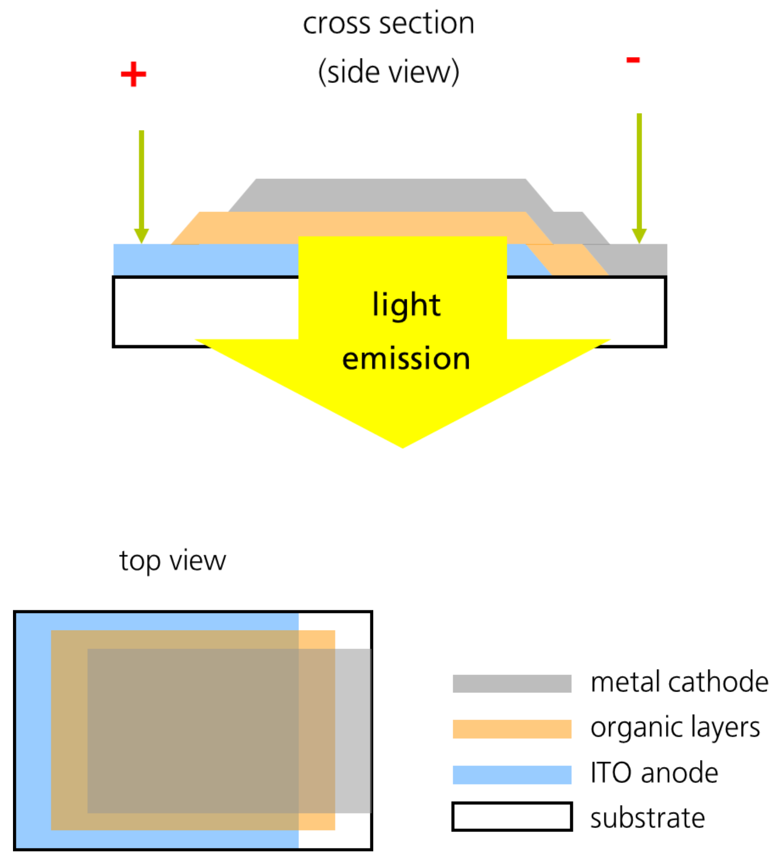
300mm R2R System

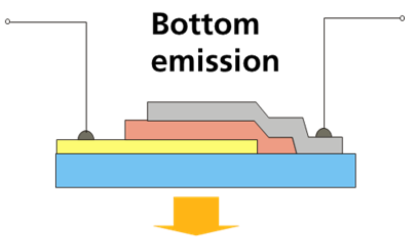
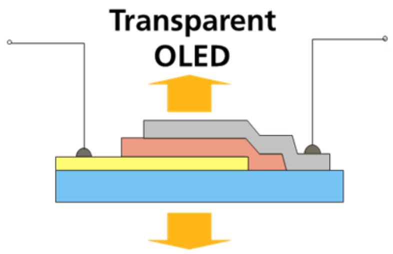
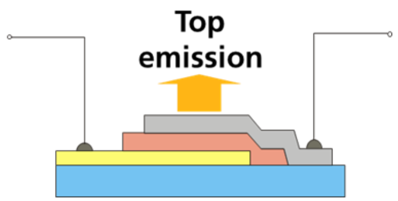


https://www.fep.fraunhofer.de/s/virtualtour/index.html

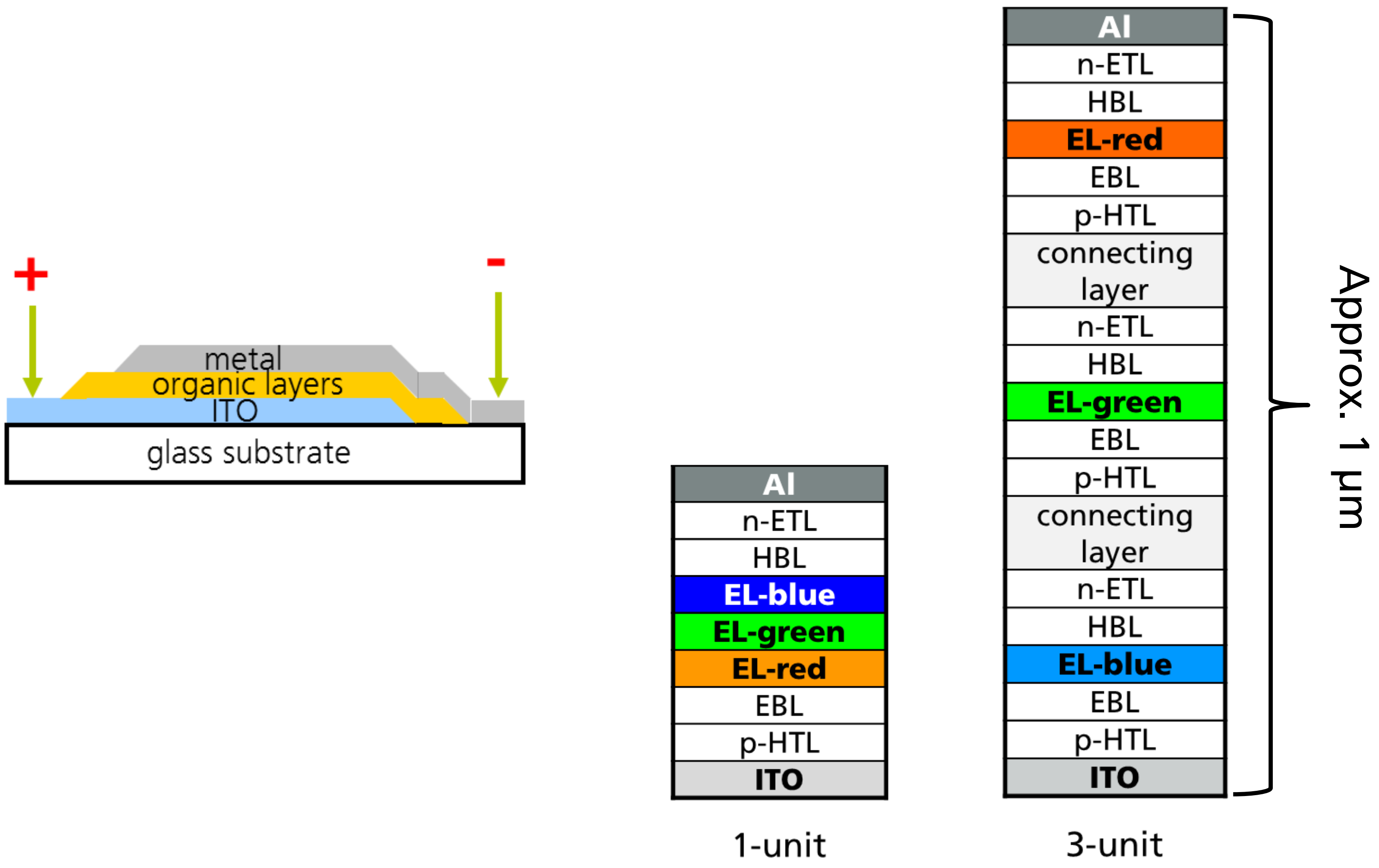
Fraunhofer FEP

OLED LIGHTING TECHNOLOGY – DEVICE STRUCTURE



	opaque top contact	transparent top contact
transparent substrate ▪ glass ▪ polymer		
opaque substrate ▪ metal ▪ Si wafer		

OLED LIGHTING TECHNOLOGY – DEVICE STRUCTURE



HTL (HIL):
hole transport layer
(hole injection layer)

EBL:
electron blocking layer

EML:
emission layer

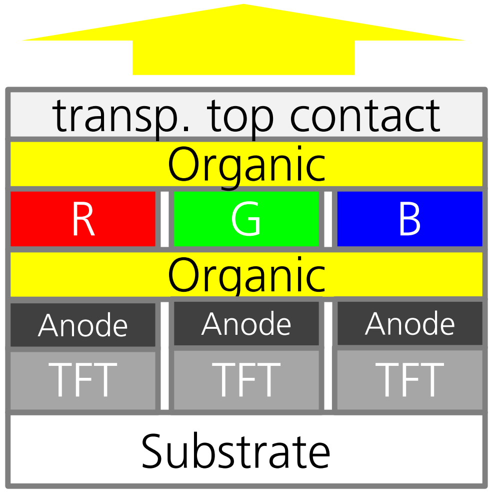
HBL:
hole blocking layer

ETL (EIL):
electron transport layer
(electron injection layer)

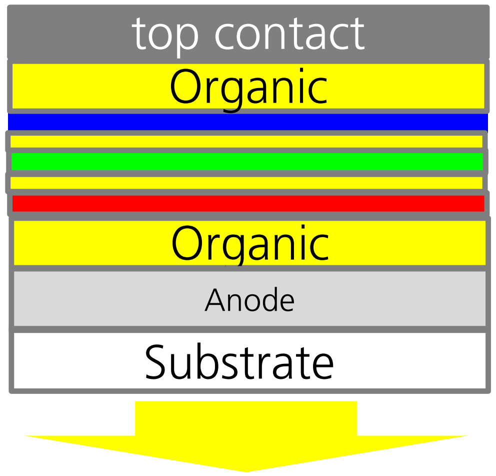
OLED LIGHTING TECHNOLOGY – DEVICE STRUCTURE

- Difference between OLED display and OLED light

Display



Lighting



Brightness: **~750 cd/m²**

Samsung Galaxy Note 10+: 1300 cd/m²

> 5000 cd/m²

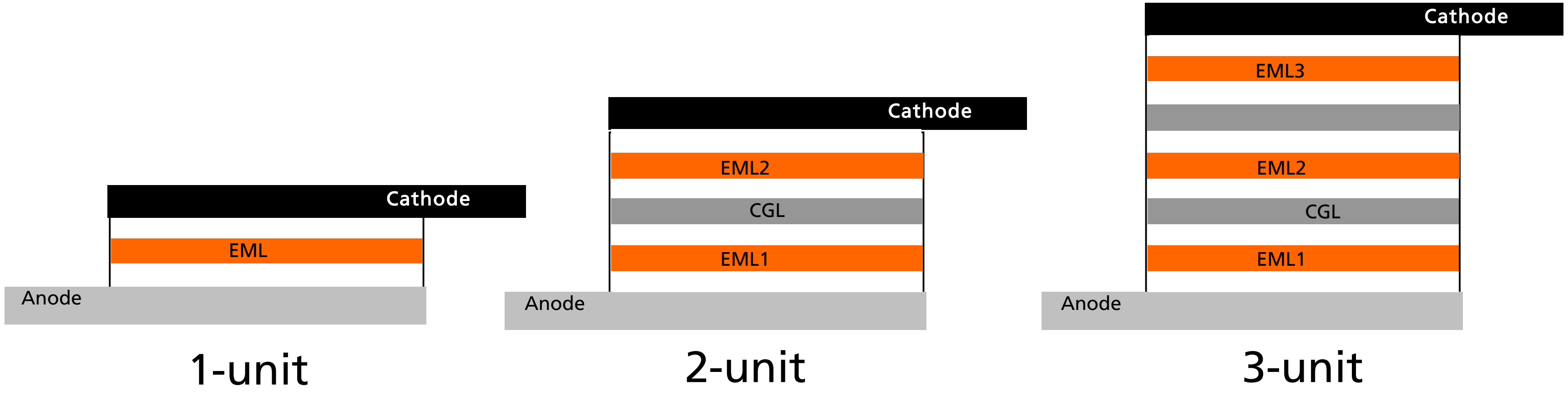
OLEDWorks Lumiblade Brite 3: 8500 cd/m²

Fraunhofer FEP

CGL

OLED LIGHTING TECHNOLOGY – DEVICE STRUCTURE

- Common high brightness approach
  - multiple OLED units
  - connected with charge generation layer



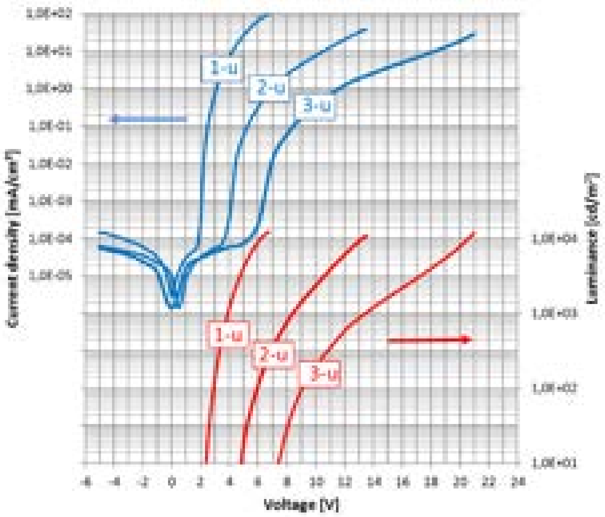
- @Fraunhofer FEP: current focus on Red and Amber

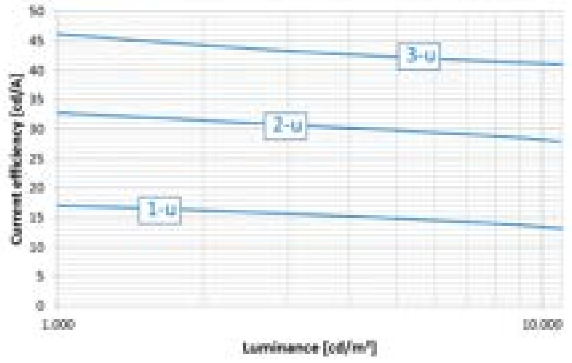
Fraunhofer FEP

OLED LIGHTING TECHNOLOGY – BRIGHTNESS

- Stacked ***RED*** and ***AMBER*** OLEDs on rigid glass

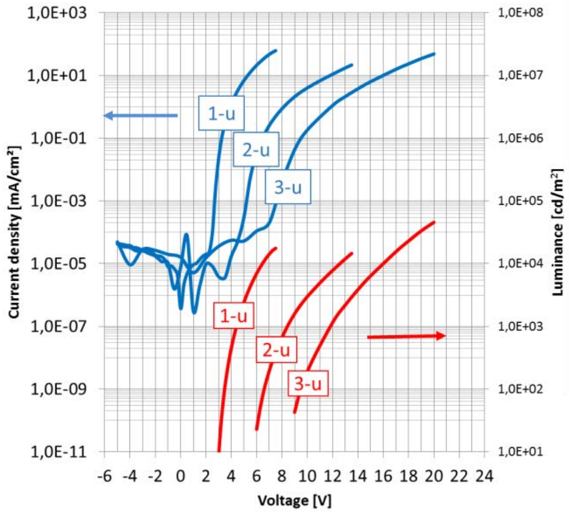
RED

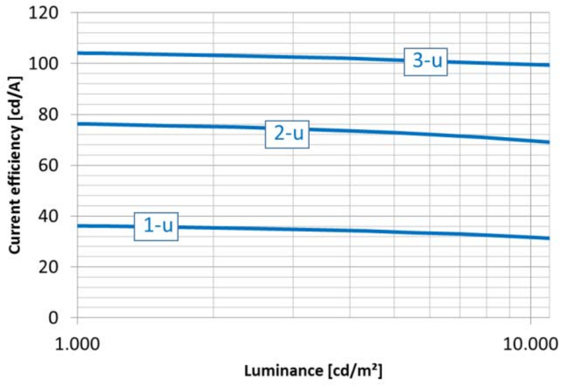




10kcd/m² @ 14mA/cm² for 2-u

AMBER





10kcd/m² @ 14mA/cm² for 2-u

- Values @ 1000cd/m²

stack	voltage [V]	CD [mA/cm²]	CE [cd/A]	C.I.E. x	C.I.E. y
1-u	3.9	5.9	17.0	0.680	0.314
2-u	8.4	3.0	32.8	0.688	0.310
3-u	13.4	2.2	46.2	0.688	0.306

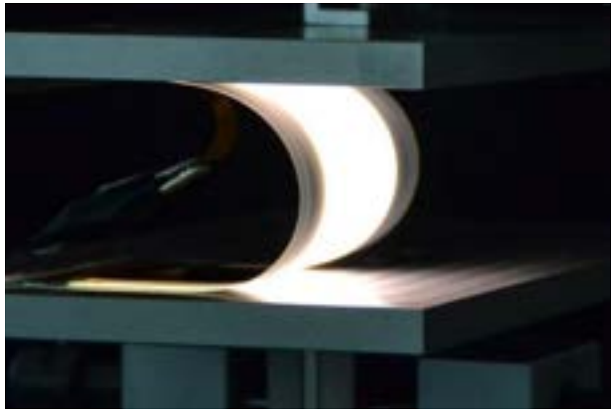
stack	voltage [V]	CD [mA/cm²]	CE [cd/A]	C.I.E. x	C.I.E. y
1-u	4.4	2.8	36.4	0.580	0.417
2-u	8.4	1.3	76.2	0.581	0.416
3-u	11.8	1.0	104.1	0.595	0.400

Phosphorescent emitter materials and technology provided by Universal Display Corporation (UDC)

Fraunhofer FEP

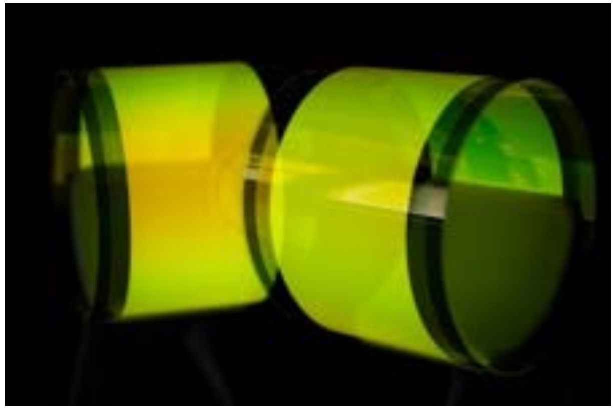
OLED LIGHTING TECHNOLOGY – FLEXIBLE SUBSTRATE TYPES

Thin glass



- typ. anode: ITO
- **Pro**:
  high temp. ITO deposition possible
- **Challenge**:
  limited bending radius, uni-axial bending only

Polymer web



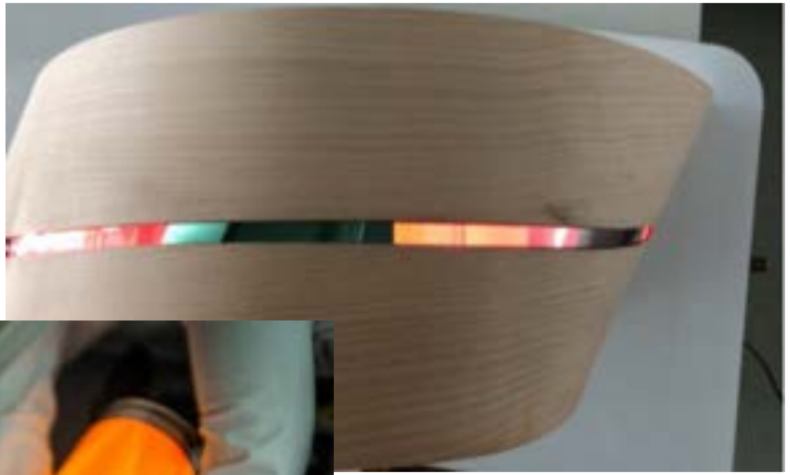
- typ. anode: IMI
- **Pro**:
  low bending radius
- **Challenge**:
  defect free barrier

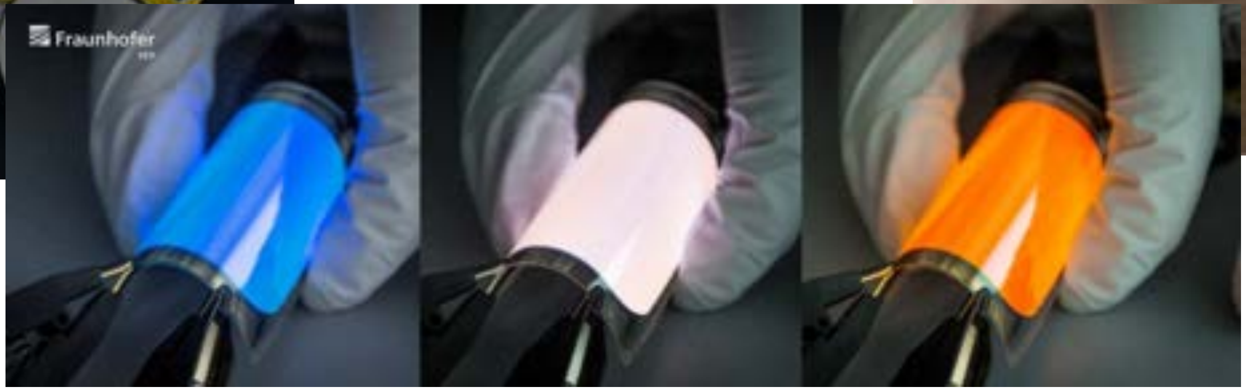
Metal foil

- typ. anode: metal
- **Pro**:
  good thermal conductivity
- **Challenge**:
  surface roughness, strong cavity (top emission)

Fraunhofer FEP

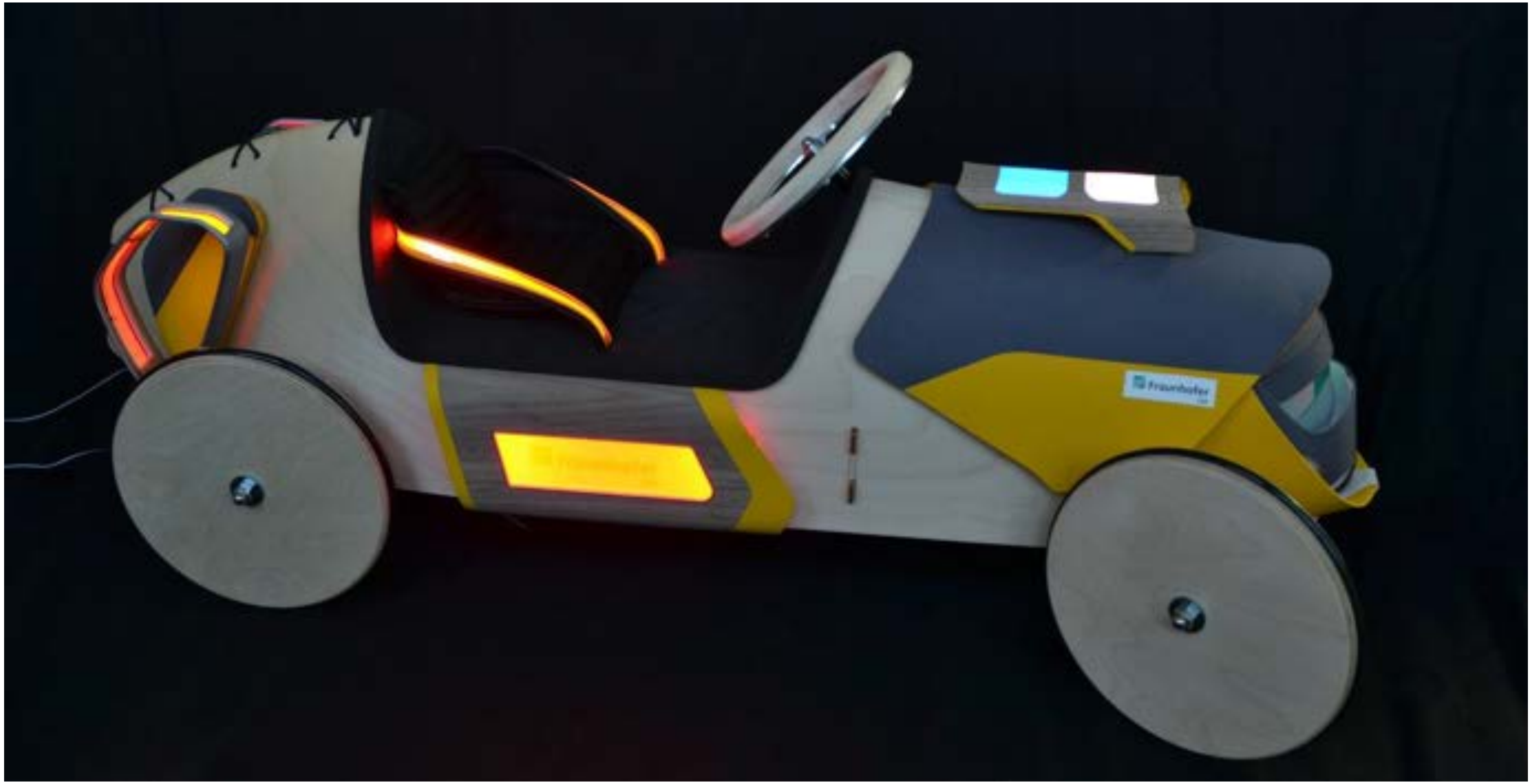
OLED APPLICATIONS





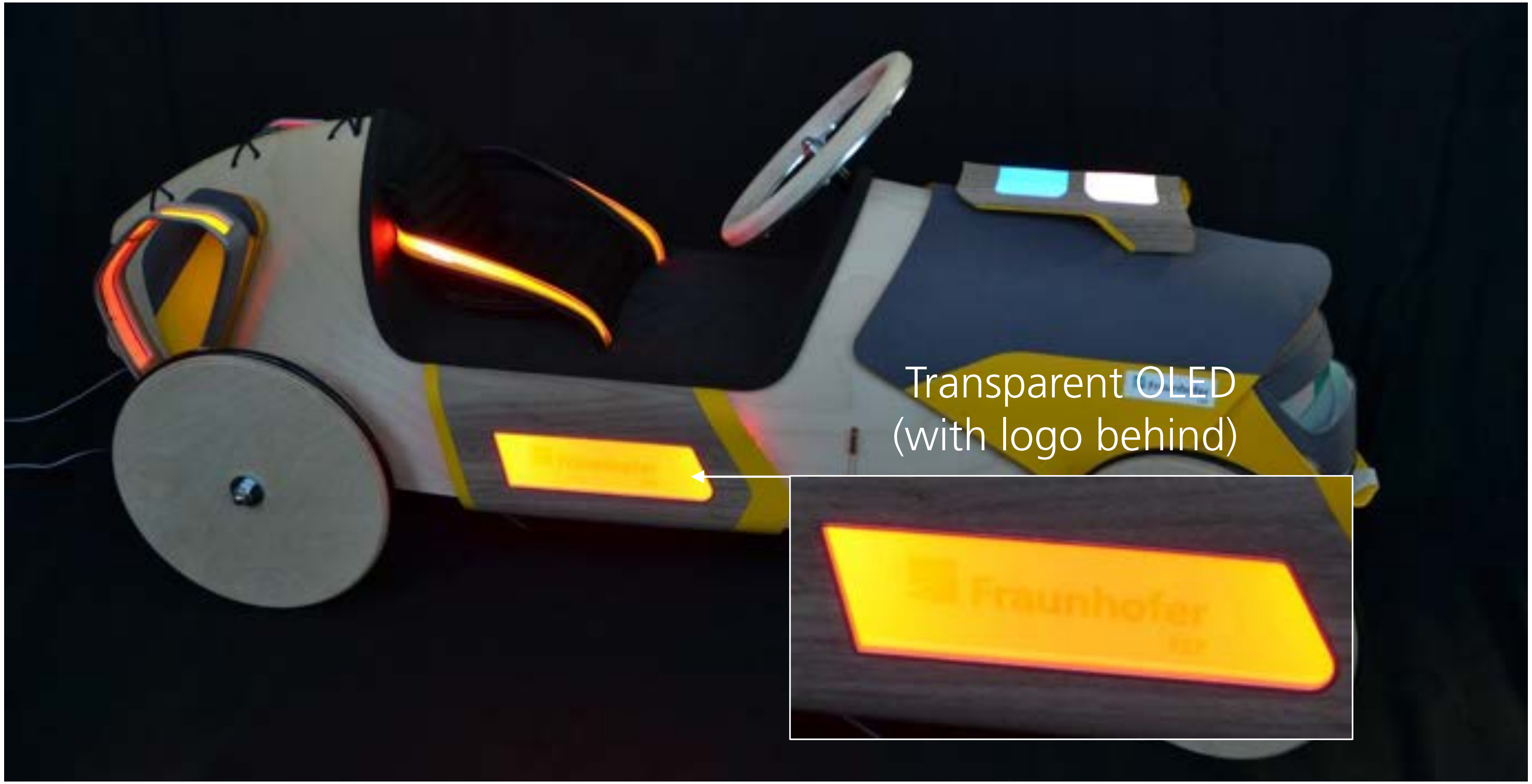
OLED LIGHTING TECHNOLOGY – AUTOMOTIVE APPLICATIONS

- Vision: more OLED features



OLED LIGHTING TECHNOLOGY – AUTOMOTIVE APPLICATIONS

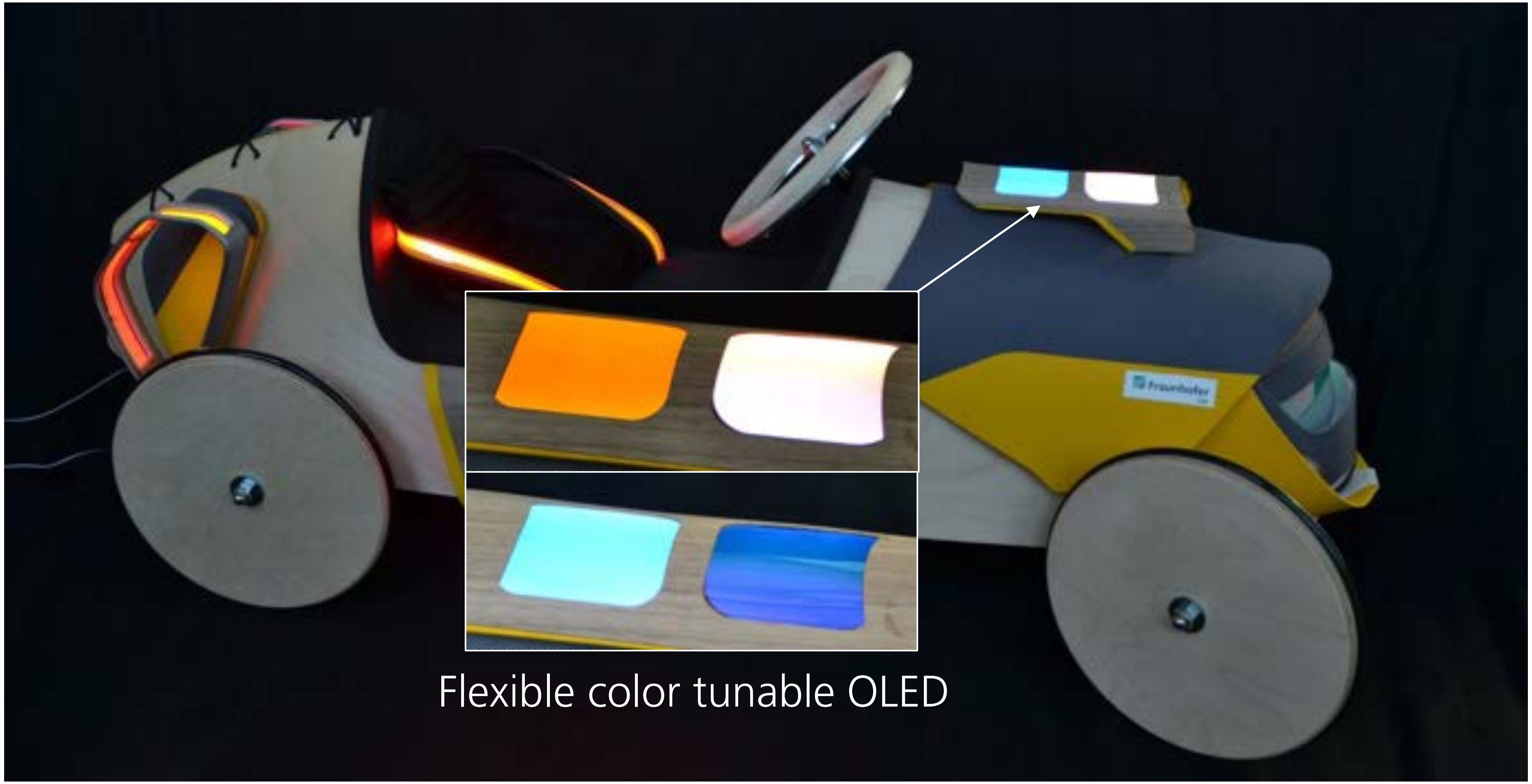
- Vision: more OLED features



Fraunhofer FEP

OLED LIGHTING TECHNOLOGY – AUTOMOTIVE APPLICATIONS

- Vision: more OLED features

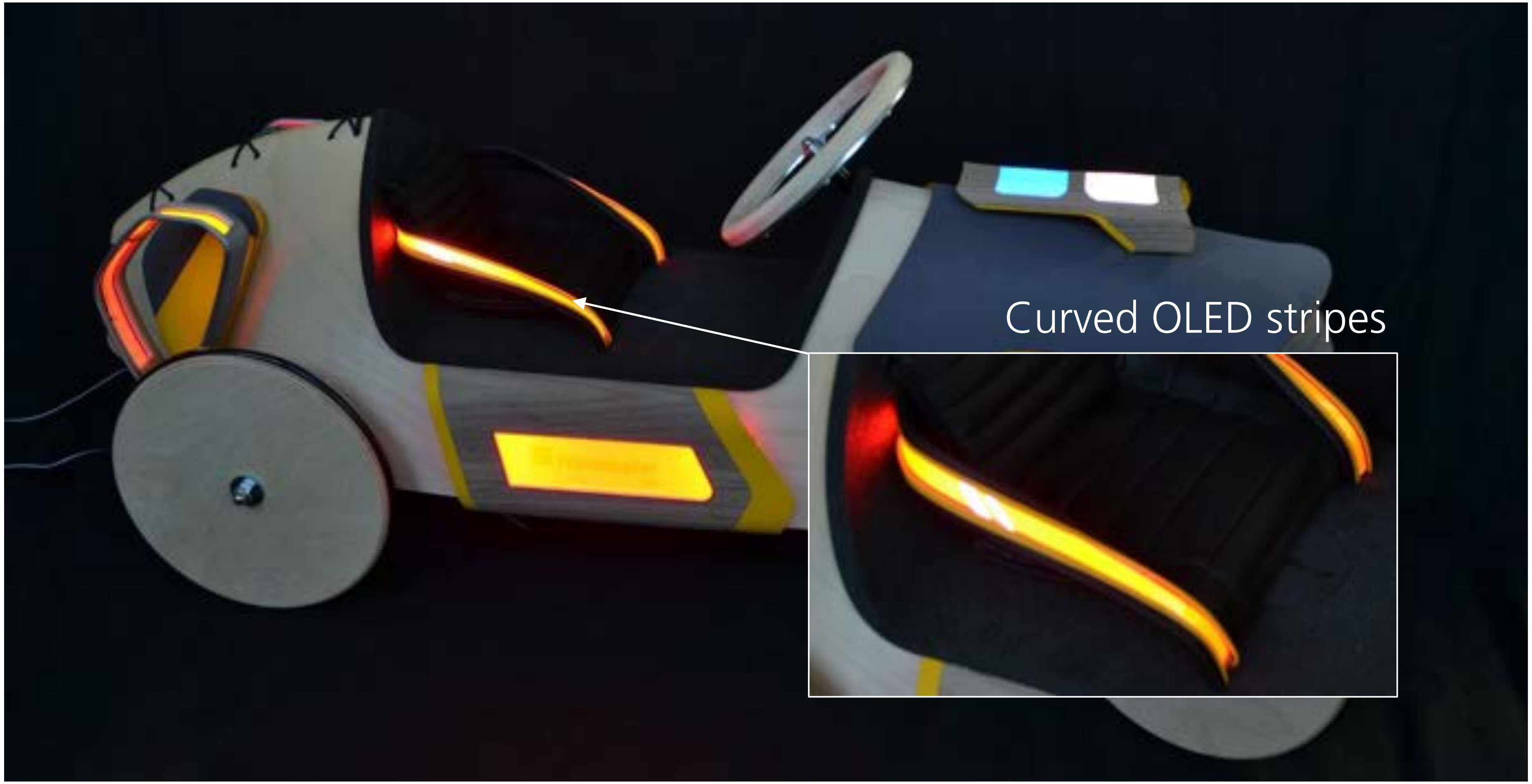


Flexible color tunable OLED

Fraunhofer FEP

OLED LIGHTING TECHNOLOGY – AUTOMOTIVE APPLICATIONS

- Vision: more OLED features



Fraunhofer
FEP

OLED LIGHTING TECHNOLOGY – AUTOMOTIVE APPLICATIONS

- Vision: more OLED features

OLED LIGHTING TECHNOLOGY – AUTOMOTIVE APPLICATIONS

- Project example: Customer specific OLED for Showcar
  - Customized OLED design & samples
    - Design and manufacturing of customer specific OLEDs (2 layouts): red/amber transparent
    - Delivery of 32 OLED modules (13x red per layout; 3x amber per layout)
    - Project duration: 20 weeks

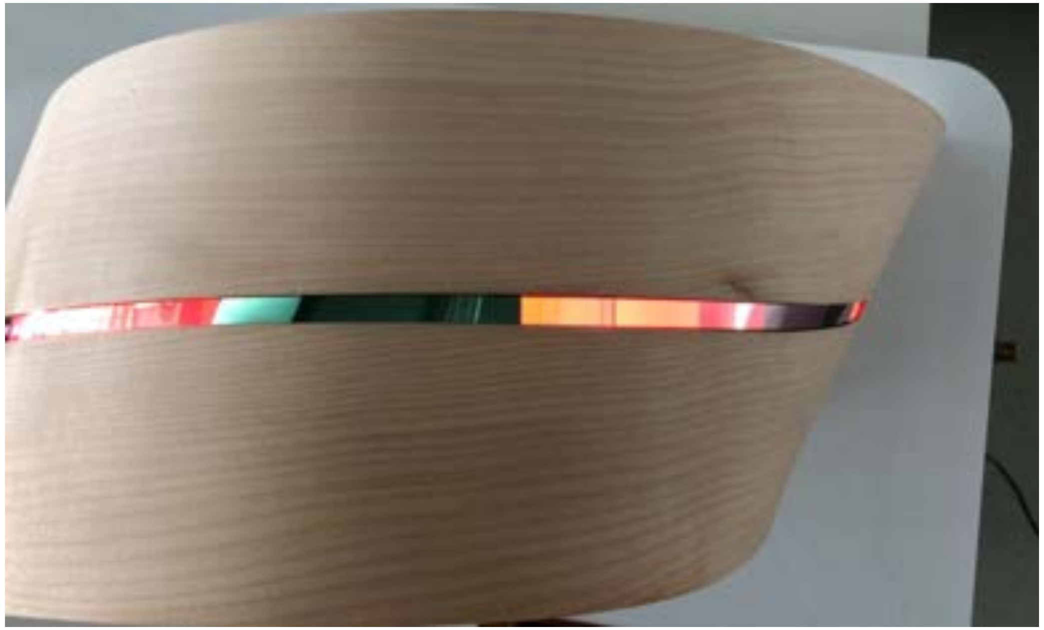
pictures/video: courtesy of R. Göschel, REHAU AG + Co

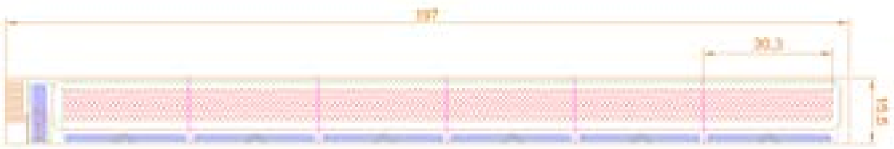
OLED LIGHTING TECHNOLOGY – AUTOMOTIVE APPLICATIONS

- Long and segmented stripes

„endless“ OLED stripes

segmented and animated light





Activities have received funding from the European Union’s Horizon 2020 research and innovation program under grant agreements No. 688093 (PI-SCALE).

Fraunhofer FEP

OLED LIGHTING TECHNOLOGY – AUTOMOTIVE APPLICATIONS

- Integrated logos and letters

SmartEEs

- OLED lighting integration into smart wood
- Touch sensitive controlling
- High brightness OLEDs from Fraunhofer
- SmartWood from Woodoo SAS

Activities have received funding from the European Union's Horizon 2020 research and innovation program under grant agreements No. 761496 (SmartEEs).

Fraunhofer FEP

OLED LIGHTING TECHNOLOGY – TEXTILE APPLICATIONS

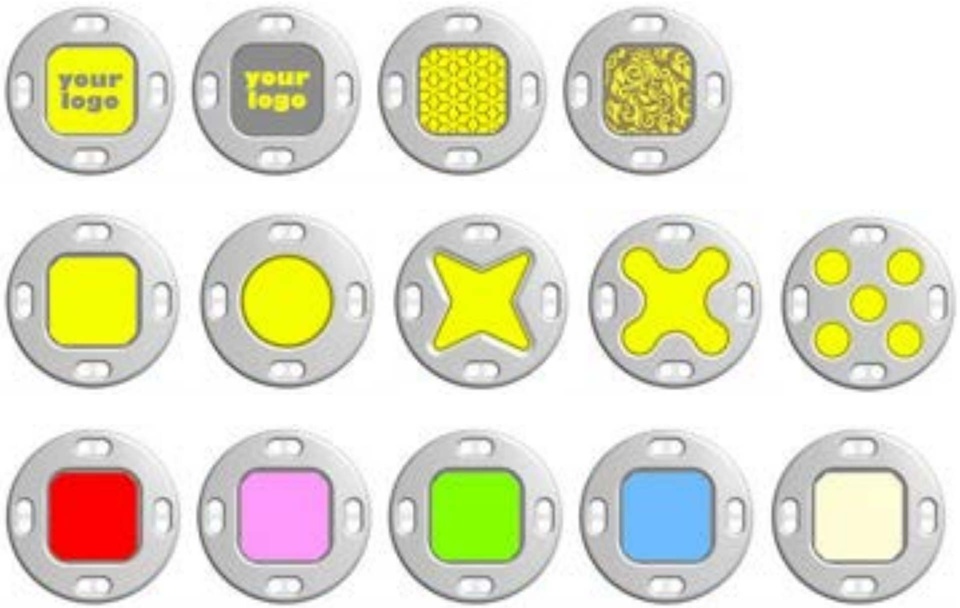
- Textile integration
  - OLED lighting = light emitting graphical elements.
  - form & feature variety of OLED lighting elements is highly attractive for the creative fashion industry, for both consumer oriented and professional!
  - We want to provide easy-to-use OLED-based lighting solutions for creative fashion industry
  - Two approaches:

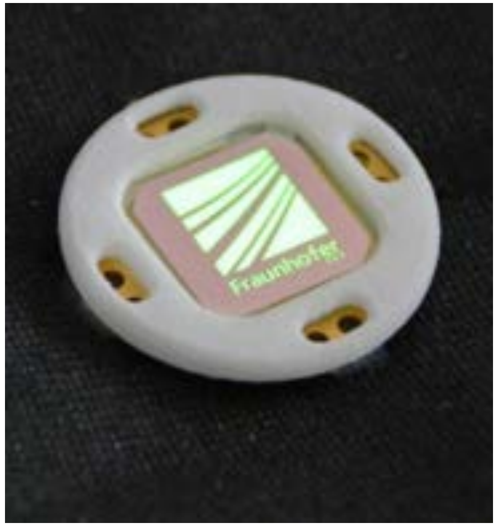
OLED button

OLED stripe

OLED LIGHTING TECHNOLOGY – TEXTILE APPLICATIONS

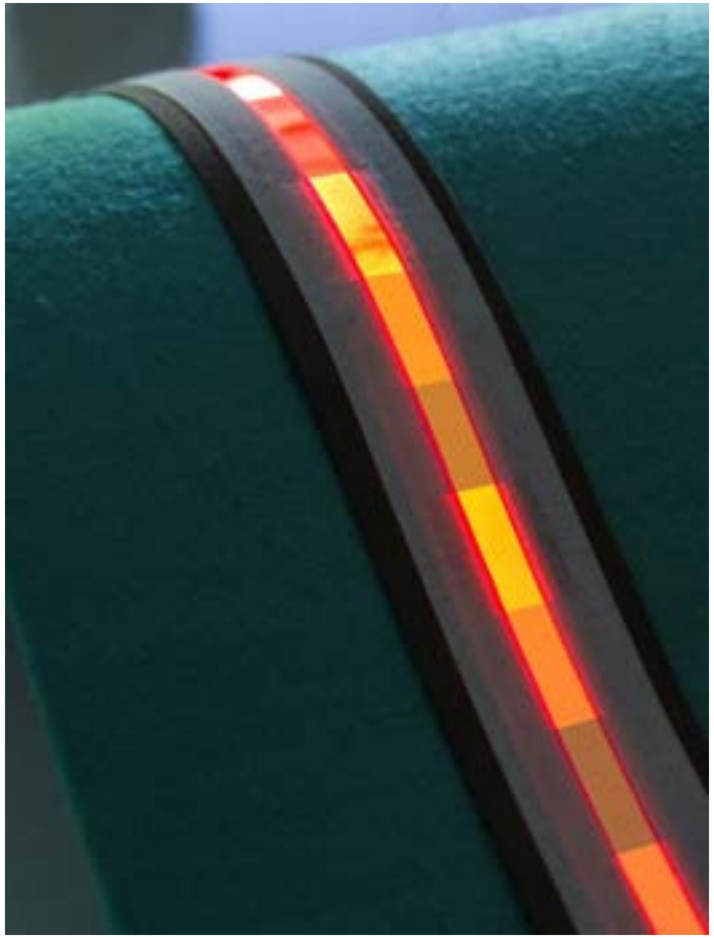
- Textile integration – OLED button
  - patterning of active area (logos, patterns)
  - various emission colours and shapes available
  - connecting with conductive yarn





OLED LIGHTING TECHNOLOGY – TEXTILE APPLICATIONS

- Textile integration – OLED stripe
  - Sew it like a textile patch!
  - connecting with conductive yarn
  - Various emission colours available
  - segmentation of lighting area



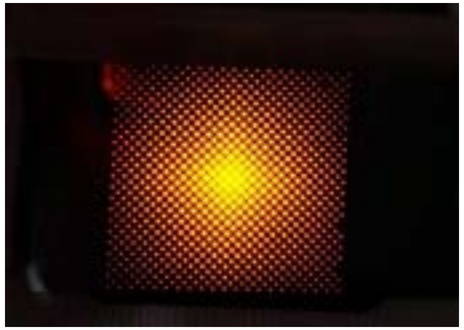
Fraunhofer FEP

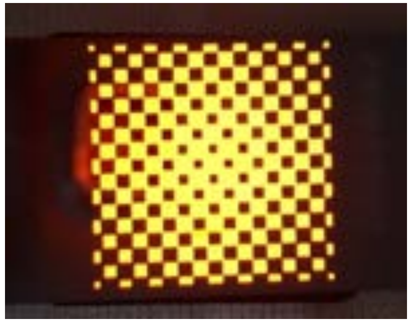
OLED LIGHTING TECHNOLOGY – LOGOS & LETTERS

- Integrated logos and letters

62 cm² OLED with logo

micro segmented 3.5 cm² OLEDs



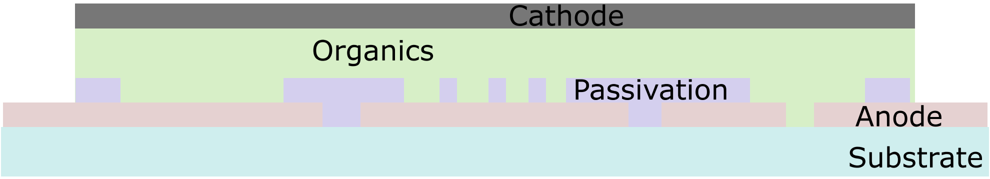


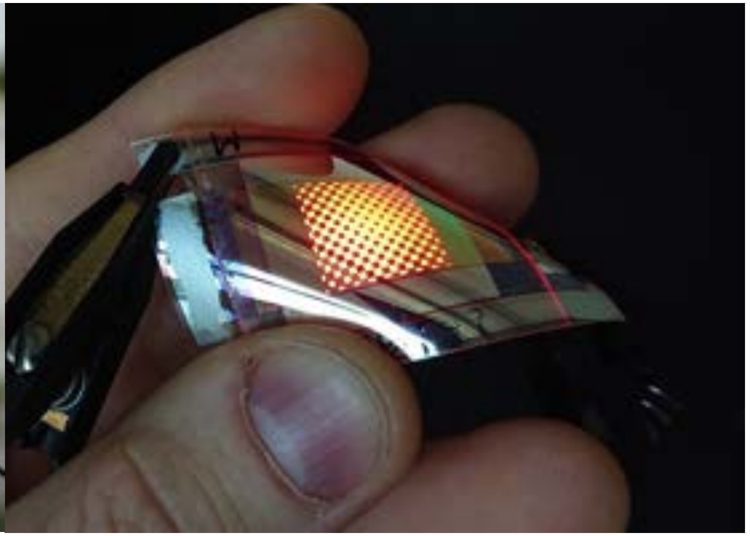
- Customized patterning by subsequent deactivation by means of a laser

- Micro patterning of the electrode before OLED coating

OLED LIGHTING TECHNOLOGY – LOGOS & LETTERS

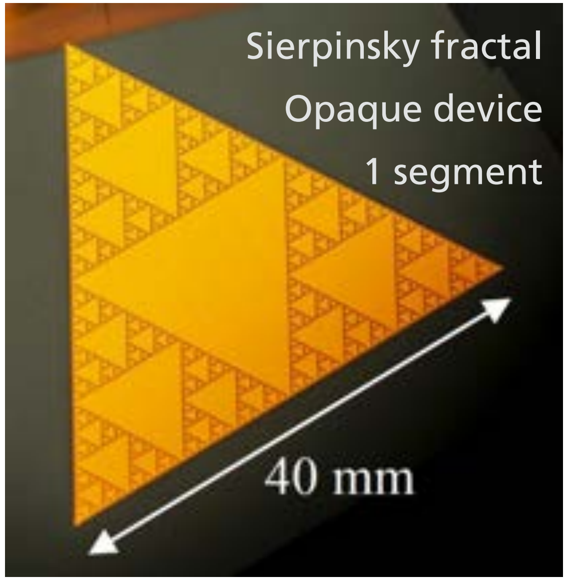
- Maskless freeform patterning via passivation and ultra-short pulsed laser ablation
  - Arbitrary emission patterns with high resolution and complete freedom of design
  - Digital process
  - Without the need for complex shadow masks
  - Feature size down to: 10 µm (emitting) / 5 µm (dark)

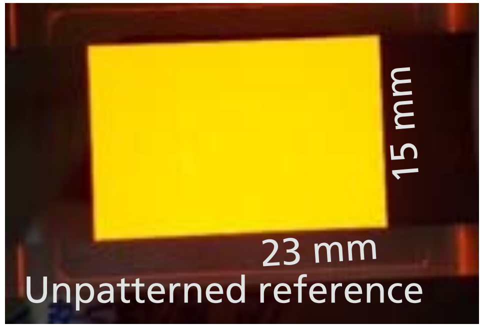


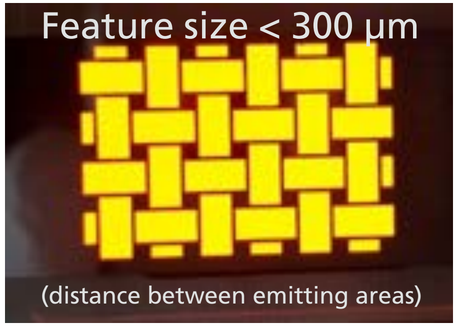


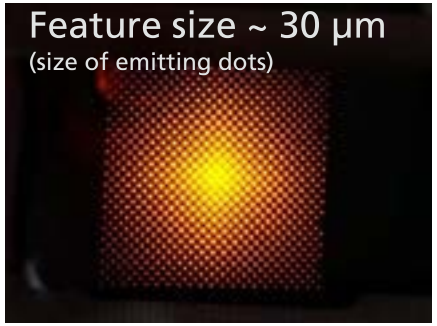
OLED LIGHTING TECHNOLOGY – LOGOS & LETTERS

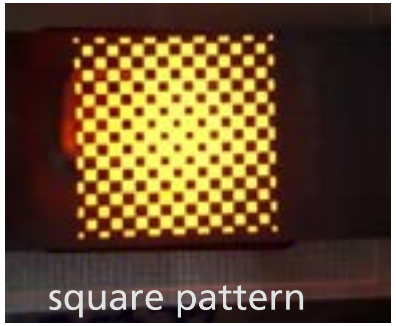
- Contact free → substrate protection
- No mechanical necessities like bridges in shadow mask
  - complete freedom of design
- Digital process
  - No cost / lost time in case of layout update
  - Laser scanning speed of about 1 m/s => complex pattern in a device of 100 cm² area can be realized in minutes
- Patterned devices in 23×15 mm²:







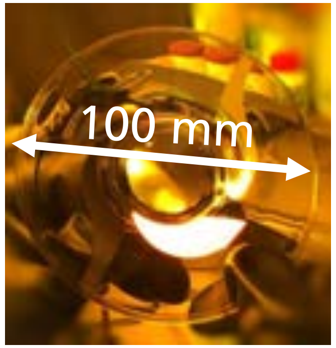




Fraunhofer FEP

OLED LIGHTING TECHNOLOGY – OLED 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

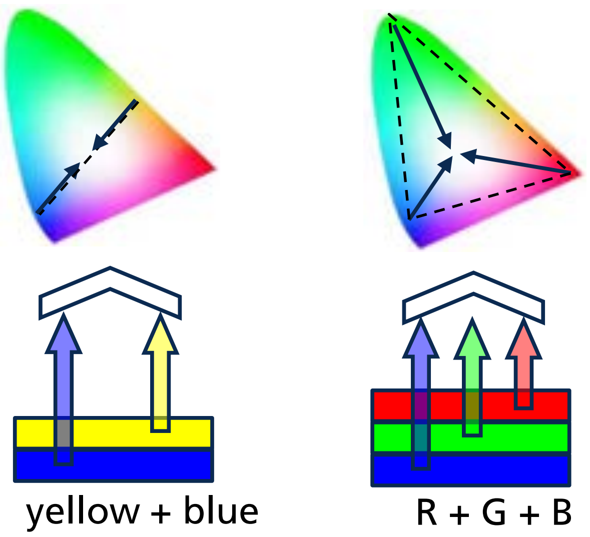


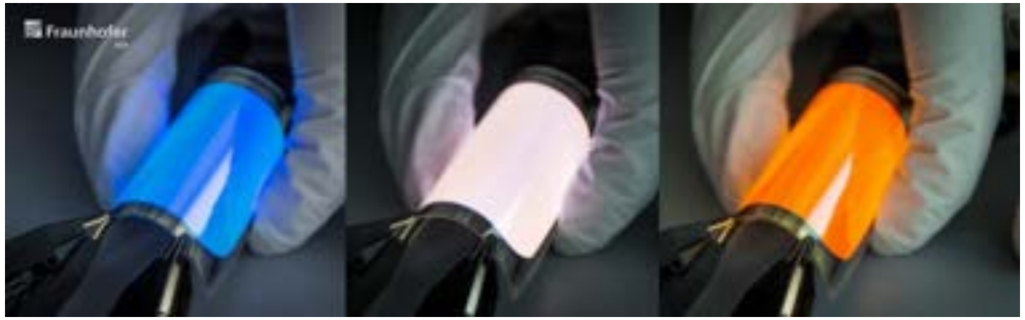
*patent pending

OLED LIGHTING TECHNOLOGY – OLED APPLICATIONS

- Color tunable OLED
  - vertical stacking of single monochrome units
    - in contrast to sub-pixel structure of RGB OLED displays or lateral sub-line structure e.g. VELVE OLED (Verbatim)
  - separate control of each single unit / colour
  - 2-color (1-Dim.) or 3-color (2-Dim.) mixing
  - individual color shade generation
  - continuously adjustable color
  - high fill factor
  - scalable to large areas, various shapes
  - flexible modules possible
  - outlook: daylight scenarios from sunrise to sunset, healthcare applications

  - See the video: www.youtube.com/watch?v=lc8gGPwVMzE





Fraunhofer FEP

Thank you very much.

Fraunhofer FEP

Dr.-Ing. André Philipp

Business Unit **Flexible Organic Electronics**

Maria-Reiche-Straße 2

01109 Dresden

Telefon +49 351 8823-478

andre.philipp@fep.fraunhofer.de

www.fep.fraunhofer.de

Parts of this work has received funding from the European Union's Horizon 2020 research and innovation program under grant agreement No. 688093 (**PI-SCALE**) and No. 761496 (**SmartEEs**).

Fraunhofer FEP