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

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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 chain 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
THE OLED: MOST SIMPLE

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

![Diagram of OLED structure]

- ITO
- α-NPD
- Alq3
- Mg:Ag

- Top view
- Cross section (side view)
- Metal cathode
- Organic layers
- ITO
- Glass substrate

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Why OLED?

Challenges:
- Cost
- Reliability

Thin

Freeform

Semi-transparent or opaque

Flexible or rigid
# COMPARISON OF FLEXIBLE SUBSTRATES FOR OLED DEVICES

<table>
<thead>
<tr>
<th></th>
<th>metal</th>
<th>ultra-thin glass</th>
<th>plastic</th>
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<tbody>
<tr>
<td>bendability</td>
<td>o</td>
<td>o</td>
<td>√</td>
</tr>
<tr>
<td>permeation barrier</td>
<td>√</td>
<td>√</td>
<td>o</td>
</tr>
<tr>
<td>roll-to-roll processability</td>
<td>√</td>
<td>(√)</td>
<td>√</td>
</tr>
<tr>
<td>surface roughness</td>
<td>o</td>
<td>√</td>
<td>√</td>
</tr>
<tr>
<td>potential of low cost</td>
<td>√</td>
<td>???</td>
<td>???</td>
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<tr>
<td>advantages</td>
<td>good barrier thermal conductivity</td>
<td>good barrier quality transparency</td>
<td>transparency high bendability</td>
</tr>
<tr>
<td>disadvantages</td>
<td>top emission additional treatment of reducing surface roughness</td>
<td>brittle device separation</td>
<td>barrier coating thermal stability residual water possible pinholes</td>
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</table>
OLED DEVICES ON STAINLESS STEEL FOIL

OLED on 50 µm stainless steel foil development in collaboration with Nippon Steel Sumikin Materials.
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.
A successful demonstration of 25 x 10 cm² OLED devices without dark spot growth! Development of proper cutting technology!
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
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
OVERVIEW PROCESS FLOW IN R2R R&D LINE

- 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.
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.

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

Total layout length 300 x 628 mm.
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

OLED key values

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<tr>
<th>Shortcut</th>
<th>Waferlabel</th>
<th>V1000 [V]</th>
<th>J1000 [mA/cm²]</th>
<th>CE1000 [cd/A]</th>
<th>PE1000 [lm/W]</th>
<th>CIEx1000</th>
<th>CIEy1000</th>
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<td>47.2</td>
<td>42.5</td>
<td>0.450</td>
<td>0.544</td>
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@ 1000 cd/m²

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<tr>
<th>U [V]</th>
<th>CE [cd/A]</th>
<th>PE [lm/W]</th>
<th>CIEx</th>
<th>CIEy</th>
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</thead>
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<tr>
<td>3.54</td>
<td>53.2</td>
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<td>0.464</td>
<td>0.525</td>
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Corresponding OLED key values on rigid glass fabricated in the cluster tool.
Consortium & Capabilities

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
The PI-SCALE pilot line service fills that gap and helps to translate your ideas into products.
R2R OLEDs

R2R evaporated OLED

- **300mm** web-width, up to 100m length
- **Good performance OLED**
- **Customised OLED shapes** possible
- **Large form factor OLEDs** possible

<table>
<thead>
<tr>
<th>Parameter</th>
<th>PI-Scale R2R evaporated OLEDs</th>
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<tr>
<td>Color</td>
<td>yellow</td>
</tr>
<tr>
<td>Luminance efficacy</td>
<td>30 lm/W</td>
</tr>
<tr>
<td>Operational lifetime</td>
<td>&gt; 500h</td>
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<tr>
<td>Shelf lifetime</td>
<td>n.a.</td>
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<tr>
<td>Operating current voltage @ luminance</td>
<td>4.5V @1000 cd/m²</td>
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<tr>
<td>Luminance</td>
<td>1000 cd/m²</td>
</tr>
<tr>
<td>CIEx/y</td>
<td>0.490/0.504</td>
</tr>
<tr>
<td>Thickness</td>
<td>thin-glass + barrier: ≈300µm</td>
</tr>
<tr>
<td></td>
<td>Barrier+ PET-ITO + Barrier: ≈420-500µm</td>
</tr>
<tr>
<td></td>
<td>Barrier-ITO + barrier: ≈320µm</td>
</tr>
<tr>
<td>Shape</td>
<td>up to 600 mm length and 290 mm width all shaped are possible</td>
</tr>
<tr>
<td>Area</td>
<td>design dependent</td>
</tr>
</tbody>
</table>
R2R Flexible Barrier Film – current status

- Pinhole density = excellent measure for barrier properties
- Standard R2R single SiNx barrier; iWVTR < $2 \times 10^{-6} \text{ g/m}^2/\text{day}$
  - $eWVTR \approx 2 \times 10^{-7} \text{ g/m}^2/\text{day}$; 0.13 pinholes/cm$^2$
- Improved R2R single SiNx barrier
  - $eWVTR \approx 1 \times 10^{-8} \text{ g/m}^2/\text{day}$; 0.03 pinholes/cm$^2$

OLED quality
R2R produced
Barrier

Pinhole results
in black spots

High quality level for barrier film manufacturing needed!
# R2R OLEDs

Ideal for low price and quantity

<table>
<thead>
<tr>
<th>R2R Evaporated OLED</th>
<th>Bottom barrier</th>
<th>Anode &amp; Structuring</th>
<th>OLED &amp; Cathode</th>
<th>Encapsulation</th>
<th>Singulation</th>
<th>Characterization and testing</th>
<th>System integration</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>HC R2R barrier, thin glass</td>
<td>ITO, ISO printing</td>
<td>OLED and Cathode evaporation</td>
<td>Lamination of HC R2R barrier</td>
<td>Roll slitting and cutting</td>
<td>Acc. shelf lifetime; Device el. characterization;</td>
<td>Component assembly, inj. molding ...</td>
</tr>
</tbody>
</table>
OLED Features Available from 2018

- Transparent OLEDs
- Long strips >1m made by R2R
- Active and passive matrix segmented OLEDs
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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