Development and Exploitation of Processes For Thin Flexible Glass

Wednesday 14th May 2014

Roll-to-Roll OLED fabrication on transparent substrates – Applications for Thin Flexible Glass

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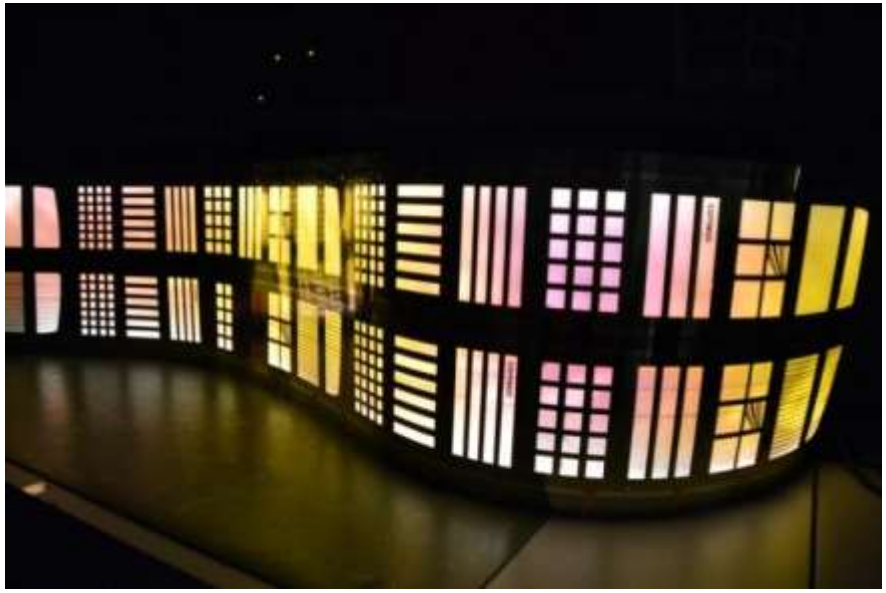
Fraunhofer Research Institution for Organics, Materials and Electronic Devices COMEDD



Workshop “Development and Exploitation of Processes for Thin Flexible Glass”

Location: M-Solv Ltd., Oxford

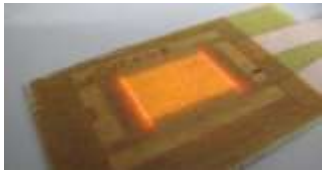
14th May 2014

Quality Management
We are certified

Fraunhofer
COMEDD

Outline

- Introduction to Fraunhofer COMEDD
- R2R OLED processing line
- R2R OLED fabrication on barrier films
- R2R OLED fabrication on flexible glass



Fraunhofer COMEDD

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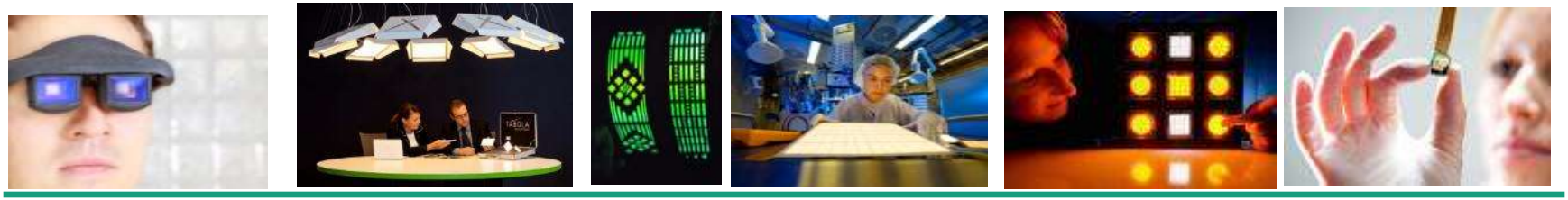


Directors

Prof. Dr. Volker Kirchhoff (acting)

Prof. Dr. Waldemar Hermel (temp.)

Figures 2013

- Permanent staff 75
- Operating budget 7.2 Mio €
- Industrial commissions 2.0 Mio €
- Basic funding 31%

Divisions

- Flexible Organic Electronics
- Microdisplays & Sensors

Fraunhofer COMEDD will merge with Fraunhofer Institute for Electron Beam and Plasma Technology (FEP) starting July 2014

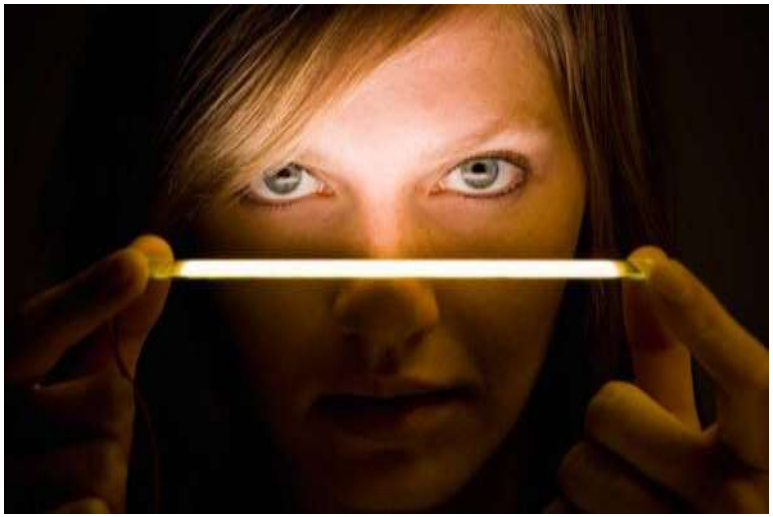
COMEDD – COMPETENCES IN LARGE AREA ORGANIC DEVICES

Process development, integration, system integration

- Large area OLED lighting panels (up to 33 x 33 cm²)
- Next generation transparent and flexible OLED and OPV modules
- Substrate patterning
- OLED/OPV processing (vacuum and wet)
- Encapsulation
- Characterization
- System design for OLED lighting modules
- Roll-to-Roll technology for OLED/OPV

Fabrication lines

- 200 mm cluster and a 150 mm batch tool for material evaluation, stack development etc.
- Gen2 line (370 x 470 mm²)
- **Roll-to-Roll line (300 mm width**)



Overview process flow in R2R R&D line

R2R inspection system

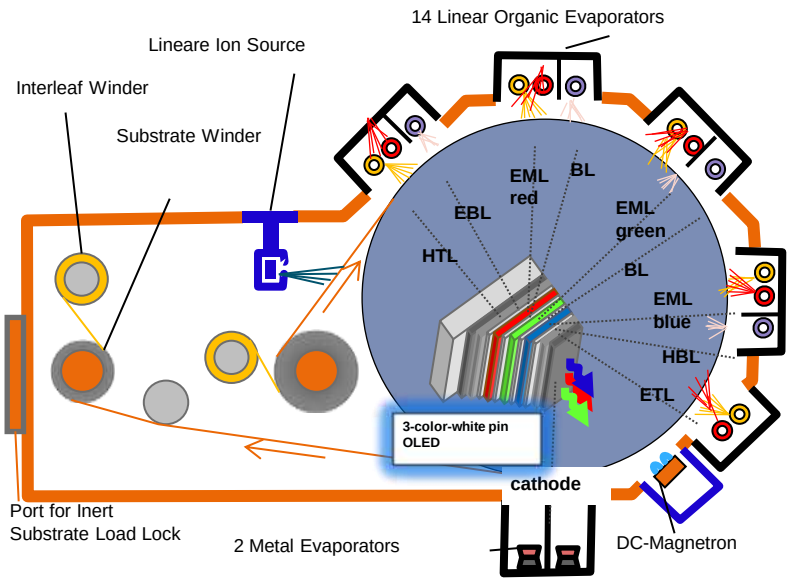
R2R vacuum coater

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 100 µm preferably (“pure” or laminated on PET)**

R2R vacuum coater for flexible OLEDs

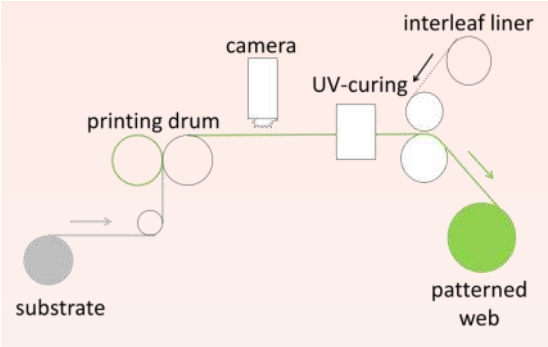


- Web speed 0.01 - 1 m/min
- Organic and metal deposition
- Co or triple-evaporation for doping
- Reactive Magnetron Sputtering of Al_2O_3
- Surface protection by liner film
- Plasma pre-treatment
- Inert transfer between vacuum and lamination unit
- Substrate heating up to 80˚C

Printing and lamination unit

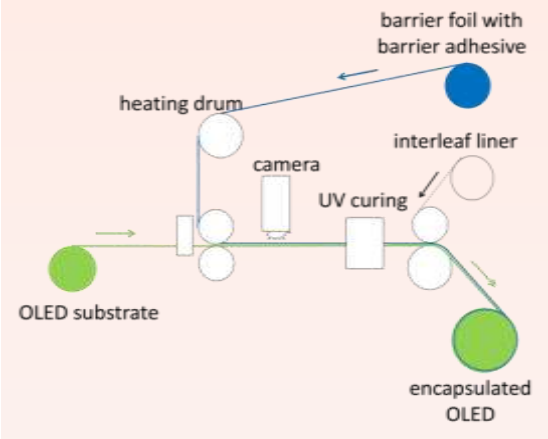
Printing:

- Print of passivation layer (layout)
- UV curing or thermal drying
- Quality control with camera
- Winding with interleaf films
- Slot die coating

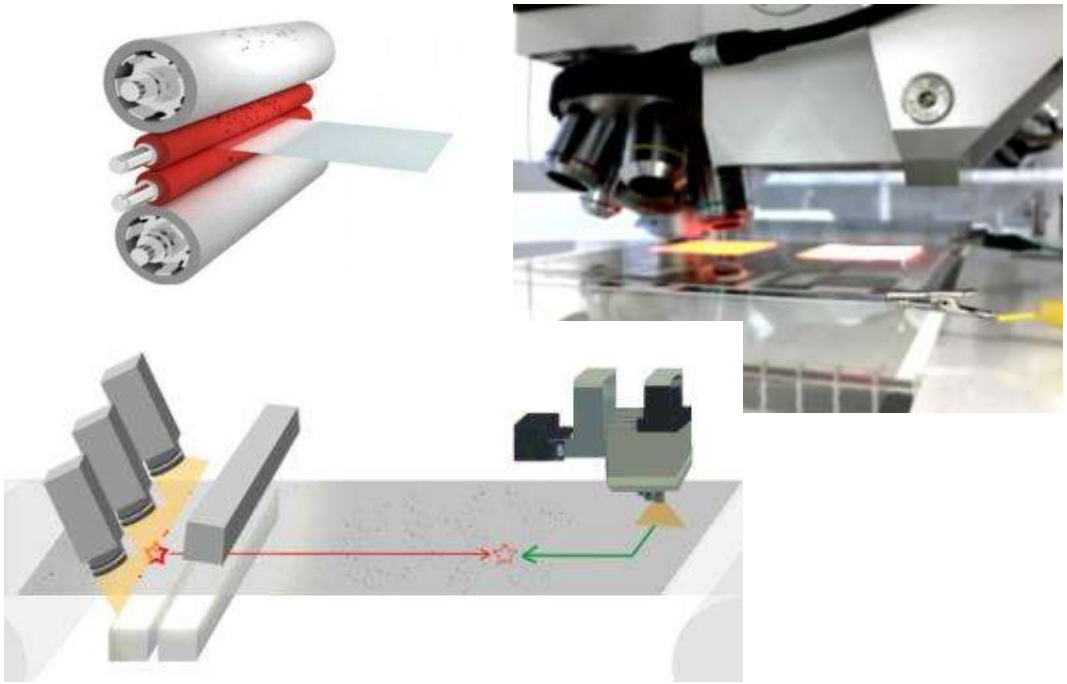


Lamination:

- Operation under inert atmosphere
- Unwinding of the self-adhesive barrier foil, removing of the protection film
- Pressing of barrier film on OLED substrate
- Curing of barrier adhesive by UV light



Substrate inspection



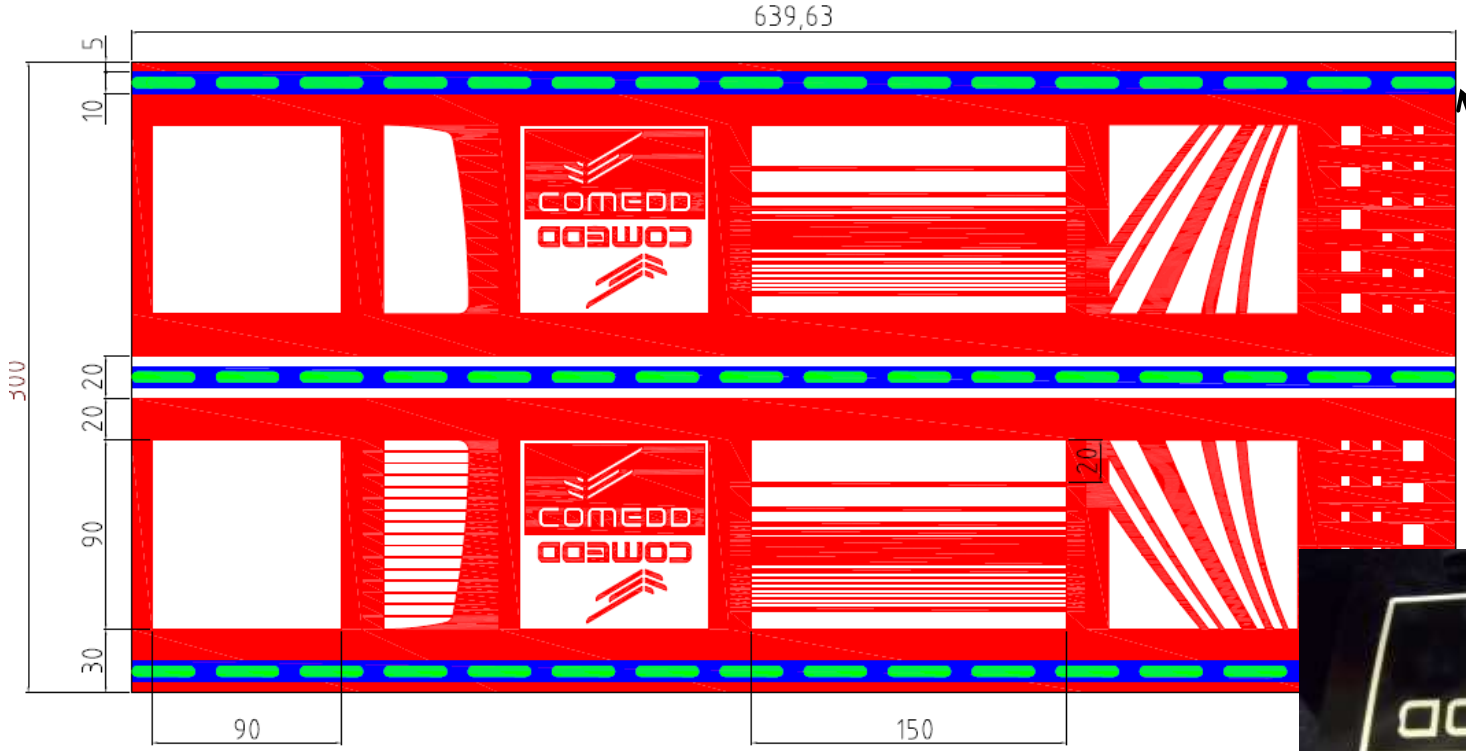
- Contactless winding of the substrate under clean room class ISO6
- Full web area inspection using line scan CCD cameras (14 µm pixel resolution)
- High-resolution inspection and defect review using movable optical microscope (≈1 µm, depends on the objective)
- Classified defects will be shown on roll map (customer specific)
- Additional characterization of substrates: AFM, confocal microscopy
- Integrated contact cleaning rollers

Flexible OLED technology status

- Challenges
  - high conductive transparent substrates for homogeneous large area OLEDs (also transparent devices)
  - lumen output (lm/W, efficacy regarding inorganic LED)
  - flexible ultra high barrier against humidity
  - high barrier adhesive for lamination of barrier
  - life time (also at elevated temperatures)
  - production costs (currently pilot lines only)
  - residual stress from the deposition of layers onto a flexible substrate + external stress from the bending – influence the efficiency?
  - stable electrical contacts for bendable devices

- **Possible solution: R2R processing of OLEDs on flexible glass???**
  - possibility of high temperature treatment of anode – high conductive ITO coated substrates
  - perfect flexible ultra high barrier against humidity (substrate + encapsulation)
  - production costs (currently pilot lines only) -> cost effective mass R2R production

Roll-to-Roll OLED layout



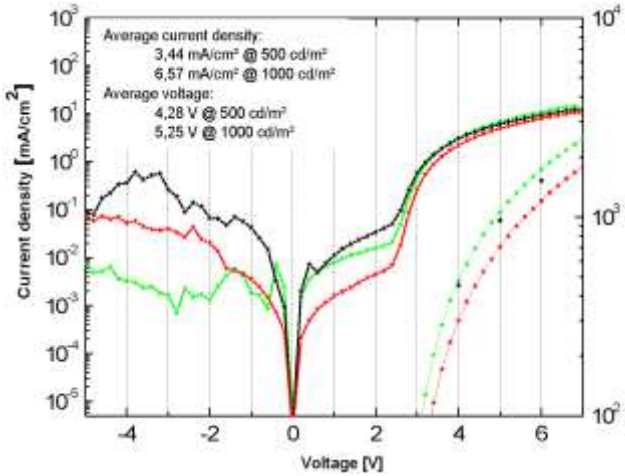
Electrode
for contacting

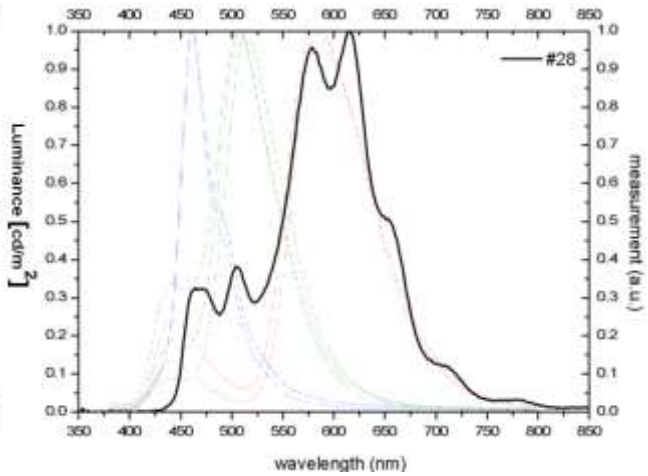
OLED on transparent substrate

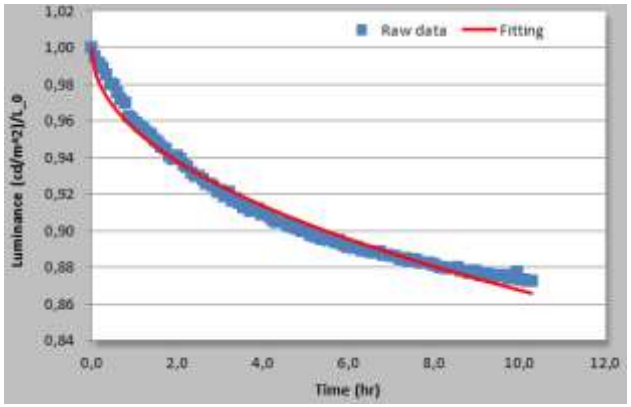
Any kind of printable active OLED lighting areas are possible:
stripes, text, rounded shapes!

R2R OLEDs on polymer barrier film - results

- process speed: 150 mm/min
- reproducible deposition process (in this case length: 20 m)
- 3 color white fluorescent stack (up to 15 lm/W, CRI 70, up to 9x9 cm²)
- encapsulation by lamination with commercial barrier foil
  (≈ high 10^{-4} - low 10^{-3} g/m²/day)
- process yield 100% (OLEDs working after deposition and lamination)
- “random leakage” current (10^{-3} up to 10^{-1} mA/cm²) -> substrate defect related (DD = 0.289/cm², line scan pixel resolution 14 µm)
- high light inhomogeneity across the substrate
- OLED lifetime LT50 in the region of ≈ 500h

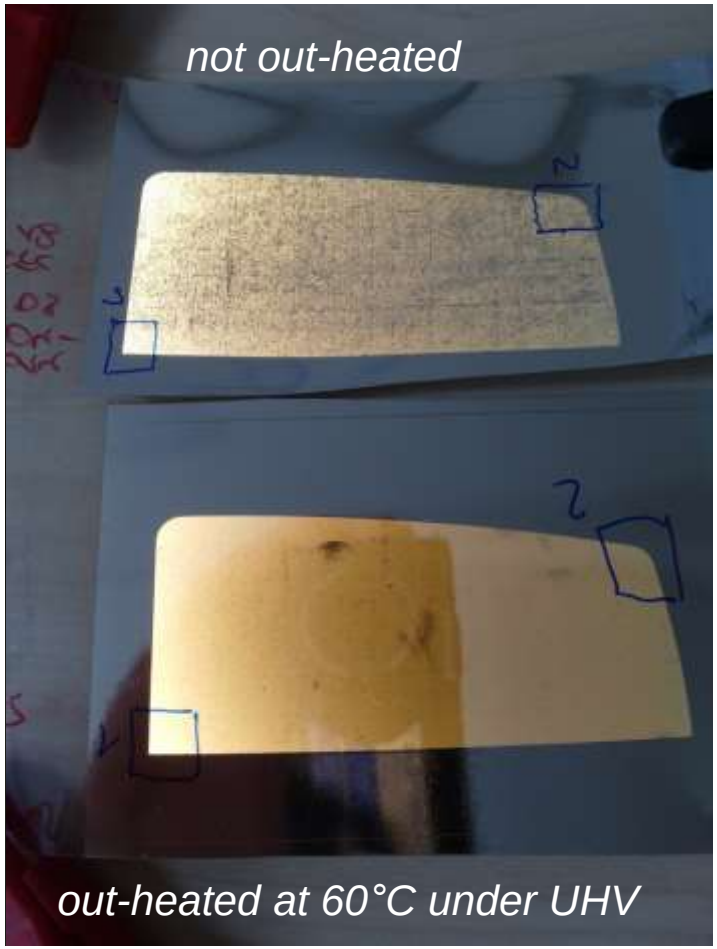




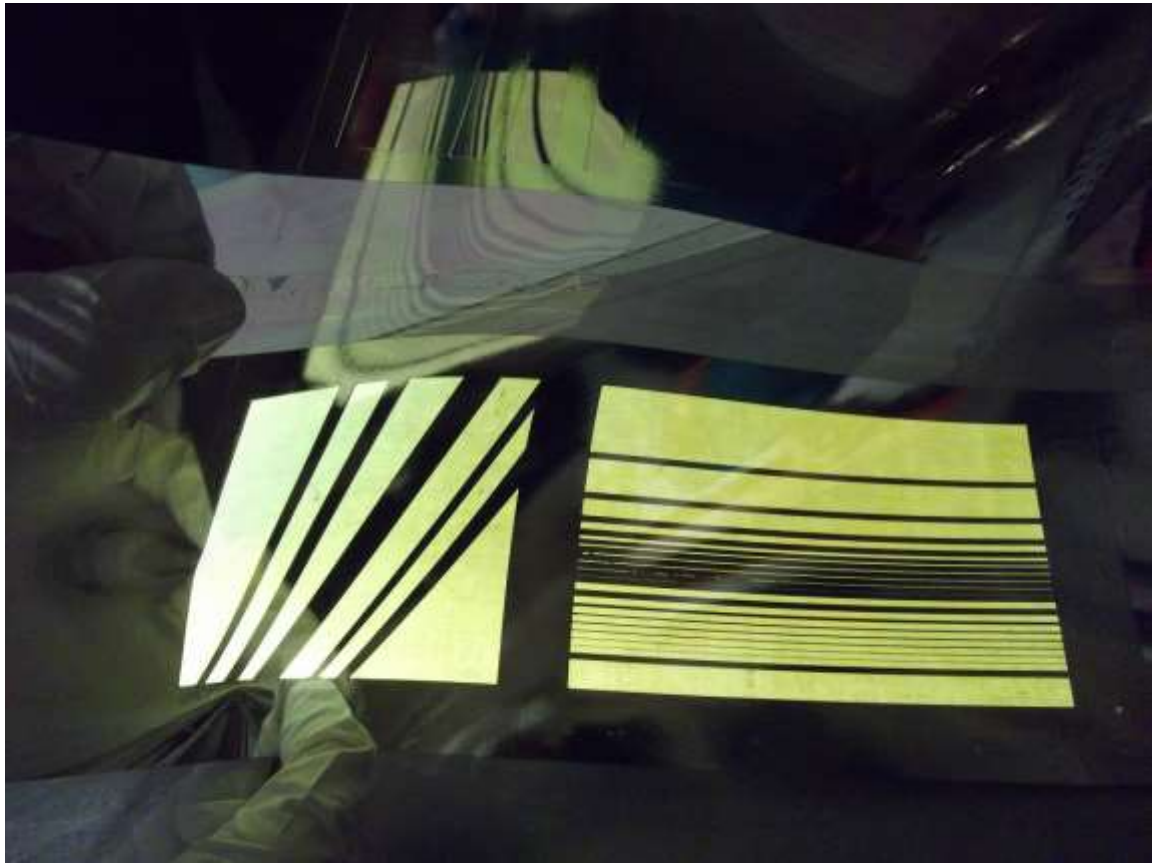


R2R OLEDs on polymer barrier film – problems & solutions (?)

- light inhomogeneity in big OLED areas
  - reason is low conductive ITO on PET
  - replace ITO by novel high conductive electrodes
  - print of metal supporting grid on the substrate (not trivial in combination with printed passivation)
- fast OLED degradation on proven “good” barrier film
  - reason might be residual water in the substrate and lamination foil/adhesive or damaging of barrier layers during R2R OLED processing
  - out-heating of substrate and lamination film before processing
  - modification of winding parameters to minimize the back contact of the substrate on the active OLED areas (patterned degradation effects)



OLED devices on novel high conductive TCO electrode

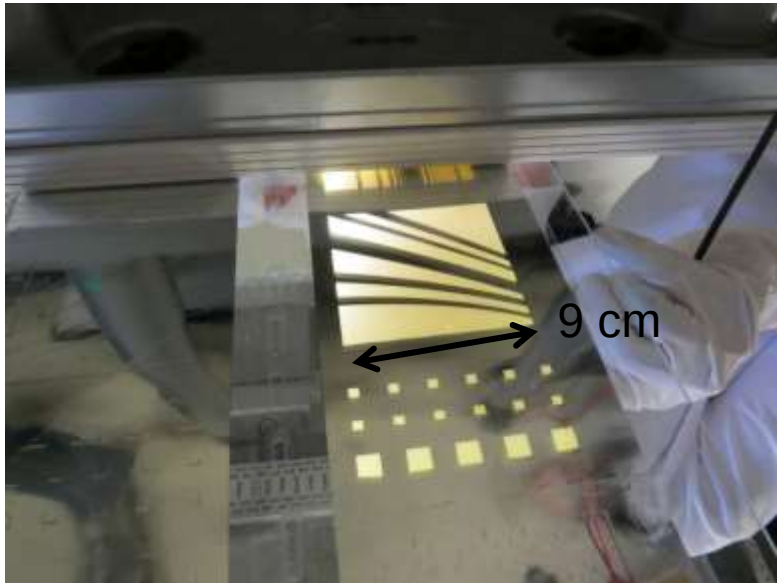


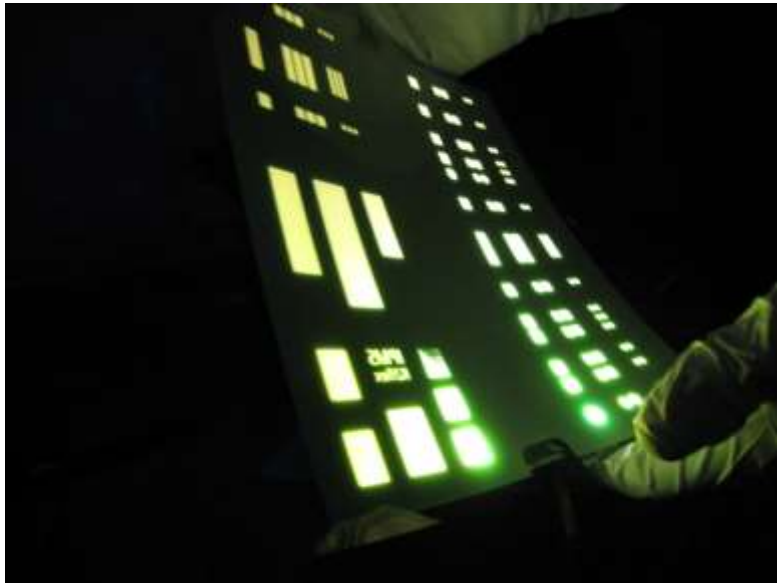
Homogeneous illumination with an efficiency of 15 lm/W!

R2R OLEDs on flexible glass - results

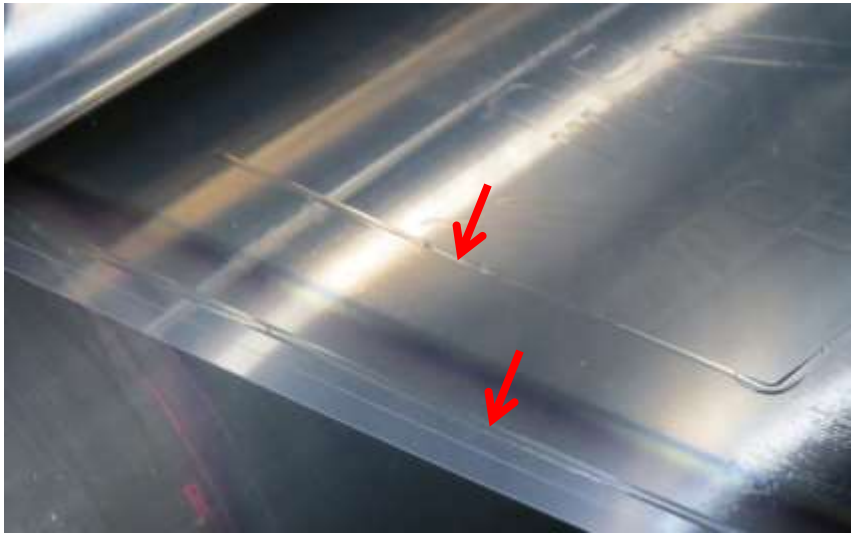
Results on sheets:

- 3 color white fluorescent stack (up to 10 lm/W, CRI 70, up to 9x9 cm²)
- OLED active areas much more homogenous due to “hot” ITO
- OLED leakage current (10^{-3} down to 10^{-4} mA/cm²) -> substrate defect density 10x smaller than for barrier films: promising regarding OLED stability and lifetime
- sheets delaminate easily from host band (process heat), they need to be stuck to the host band precisely: future R2R deposition on “pure” glass rolls

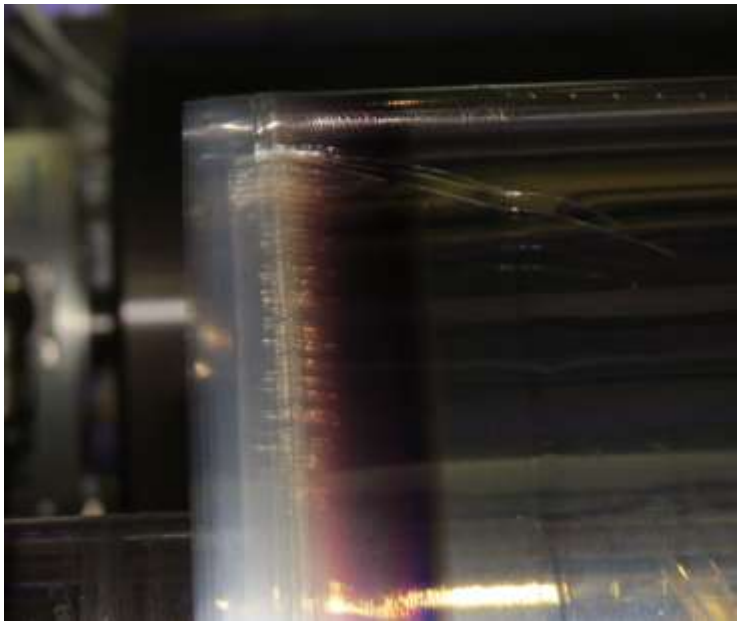




Printing on flexible glass



Printing edge with hillock (highlighted by the red arrow)



After re-winding cracks appeared, by the hillocks at the edge.

Very high precision of the printing unit is needed
with a thickness- and parallel accuracy ≈ 10 – 20 µm.
→ Printing on flexible glass is still challenging (parallelism and tape guiding) !

Conclusions and outlook

- Summary:
  - Both polymer barrier films and flexible glass are very promising substrates for organic devices.
  - flexible glass seems to have a factor of 10 – 15 lower defect level in contrast to barrier films (needs further verified)
  - The leakage current of OLED devices on flexible glass is (10^{-3} down to 10^{-4} mA/cm²) and on barrier films (10^{-3} up to 10^{-1} mA/cm²) → more statistic is needed.
  - Much higher process temperature on flexible glass is possible for “hot” ITO and drying in contrast to polymer films.
  - On flexible glass needs a high index for good light out-coupling (light management)
  - Lamination of flexible glass on PET helps to optimize the R2R web handling
- Outlook:
  - focus on flexible glass for the encapsulation → **How to perform laser drilling to get electrical contact?**
  - first R2R OLED runs on “pure” and PET laminated glass roll substrates are planned
  - further understanding of correlation between defect density, dark spot formation, device performance and barrier properties
  - goal for 2015: white OLED with LT50 of 10 kh and efficacy of 25 lm/W

LUMINALE 2012, Frankfurt/M., Palmengarten

Thank you for your attention!

COMEDD

We shape the light.