R&D Tools for OLEDs & Next Gen PV

- Easy-to-use simulation software **setfos** able to simulate OLEDs and thin film PVs on the small scale/cell level.

- Easy-to-use all-in-one characterization platform **paios** to extract device and material parameters by dynamic characterization.

- Easy-to-use large-area simulation software **laoss** able to simulate OLEDs and solar cells up to the module scale.
Impedance Spectroscopy

Photo-CELIV

Capacitance-Voltage

Dark Injection Transients

Transient Photovoltage

Charge Extraction

IV-Curves

Transient EL

Transient Photocurrent

IMPS

IMVS
SoA OLEDs for Lighting

Lumiblades (OLEDWorks)

LG Chem

OSRAM

Audi TT OLED rear light
OLED R&D Challenges

- Light-outcoupling (scattering...)
- Efficiency roll-off at high currents
- Exciton harvesting (TADF instead of phosphorescence)
- Driving voltage (power consumption)
- Device degradation
- Upscaling to large-area
OLEDs & Self-heating & roll-off?

- OLED lighting: Though no heat sink is needed, some heat is produced!
- Heating is an issue in OLED displays, too:  
  
  \[ \text{J. C. Sturm, IEEE JSTQE 4 1 (1998)} \]

- Suppression of Joule heating in narrow OLEDs reduces efficiency roll-off!

\[ \text{Hayashi, Adachi, Appl. Phys. Lett. 106, 093301 (2015)} \]
PAIOS with Angular Spectrometer Module for (O)LED Emission Analysis
OLED Emission Zone Fitting Example

Phosphorescent OLED

OLED stack

Angular Emission Spectra

Measurements: paios
Simulations: setfos

Monitor:
• Dual-peak emission zone in EML
• Emission zone shift to HTL/EML at high current density
• Correlation to efficiency roll-off, aging mechanisms, emitter orientation

by Markus Regnat, ZHAW
Excitonics in (TADF) OLEDs

- Thermally activated delayed fluorescence (TADF) OLEDs as alternative to phosphorescent OLEDs
- Example simulation with **Setfos**: Temperature variation

![Normalized emission graph](image)

![CIE color diagram](image)

![Device efficiency graph](image)
OLED R&D Challenges

- Scatter foil improves brightness but changes color & angular dependence
- 10 cm x 30 cm OLED by LG Chem
- Metal grid enhances conductivity but shadows light

Optical simulation (Setfos)

Electrical large-area simulation (Laoss)
OLED Panels w/ Light Extraction Foil – LG Chem Example

Angular Luminous Intensity (measured by paios)

Angular Corr. Color Temp. CCT (measured by paios)

2850 K
2450 K
2050 K

Viewing Angle

With scatter foil
Without

x 2.1

Scatter foil and OLED stack need to be **jointly** optimized!
Summary of Simulation Workflow

1. **Scattering structure**
   - Examples: textures, particle scattering, micro- and nano-structures

2. **Bi-directional Scattering Function (BSDF)**
   - Experiment or simulation

3. **Design & optimize the OLED structure**
   - Haze=1

![Bi-directional Scattering Function](image)

Wavelength (nm) vs. Angle
Top-emitting flexible OLED with thin film encapsulation & scat. foil

- Optional (commercial) outcoupling foils from Dupont Tejin Films with embedded particles were applied.
- Foils with different haze (9% vs. 59%) were used.

Excellent Agreement between Experiment (Holst) and Simulation (Setfos)

- Angular luminance increases with haze

- Blue color (no scatter foil) turns into white (with scatter foil)

S. Altazin (Fluxim), S. Harkema (Holst Centre)

Optimization of the PET Scatter Foil

→ Easily sweep the particle parameters to optimize the device.

→ Maximum of luminance for a particle concentration = 2.75 E-3
→ The luminance and emitted color can be optimized at the same time
→ Maximum because of backscattering and absorption by the particles

SETFOS can compute the BSDF of rough surfaces for both I. E. I., and E. E. I.

Less scattering for I. E. I. because of smaller index difference.
Simulation of White OLED with Rough Interfaces

→ Using two rough interfaces increases the emitted lumens by 2.1.
→ The emitted color remains white with the scattering interfaces.
Getting the BSDF of a textured interface from simple optical measurement & Setfos

→ Usually BSDFs are difficult to measure.

Access surface properties from normal incidence transmission

Experiment (ZHAW)

→ We just need angular transmission data at normal incidence to calculate the BSDF
Multi-scale, Multi-physics OLED Modeling

Length Scale

- cm
- mm
- um
- nm

Electrical

- electro-(thermal) FEM model
- Drift-diffusion model (1D vertical)
- Monte-Carlo

Optical

- 3D Ray-tracing
- statistical microtexture
- Dipole emission & thin film optics
- Full-wave

Thermal

- macro
- nano
- micro
Laoss: Design of large-area panels
LAOSS: FEM Method

→ We do a 2D+1D coupling instead of 3D:
  - import a 1D IV curve (from a small device)
  - and solve Ohm’s law in the large 2D anode by FEM.

Calculates:  
Input quantities
Output quantities

Electric potential distribution

IV curve of the module
OLED Panel Example

Without (left) and with (right) metal grid

10 cm x 10 cm OLED panel

Simulation Workflow with Laoss

- Draw and import the device geometry (.dxf file)
- Run meshing
- Import local IV curve & enter electrode conductivity
- Run the simulation

Alternative:
Parametrized, pre-defined layouts
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Commercial R&D tools for OLEDs and solar cells
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