Zurich University
of Applied Sciences

School of
Engineering

ICP Institute of
Computational Physics

FLUXiM
www.fluxim.com

Design and Optimization of OLED Light-outcoupling Enhancement Structures

Beat Ruhstaller
Fluxim AG / ZHAW

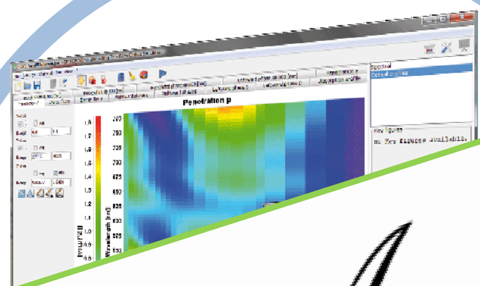
Muttenz, 30.10.2014

Who we are

Zurich University of Applied Sciences
School of Engineering
ICP Institute of Computational Physics

FLUXiM
www.fluxim.com

n Software



setfos 10th Anniversary 2004 - 2014

paios

Measurement Hardware

Research on OLED and OPV

AEVIOM

IM3OLED
RESEARCH FOR SUSTAINABLE LIGHTING

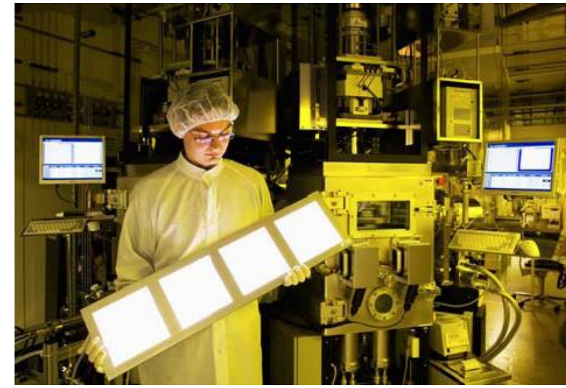
Sunflower

swiss made software

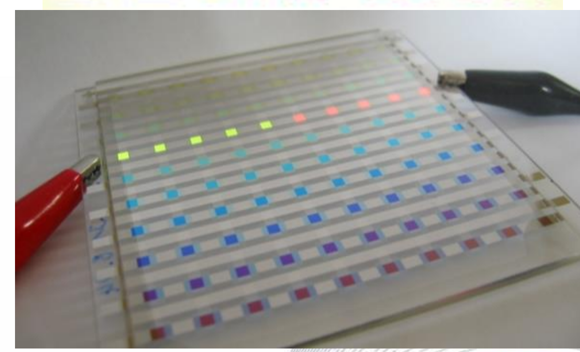
Our Customer‘s Pain

- Which problem do we solve?
  - **Cumbersome** and **costly trial-and-error** optimization
  - **Unlimited** material and device **configurations**
  - Monitor/control quality
  - Understanding of operating mechanisms

- Our solution:
  Virtual experiments on a PC with easy-to-use **software** and all-in-one measurement **hardware**!



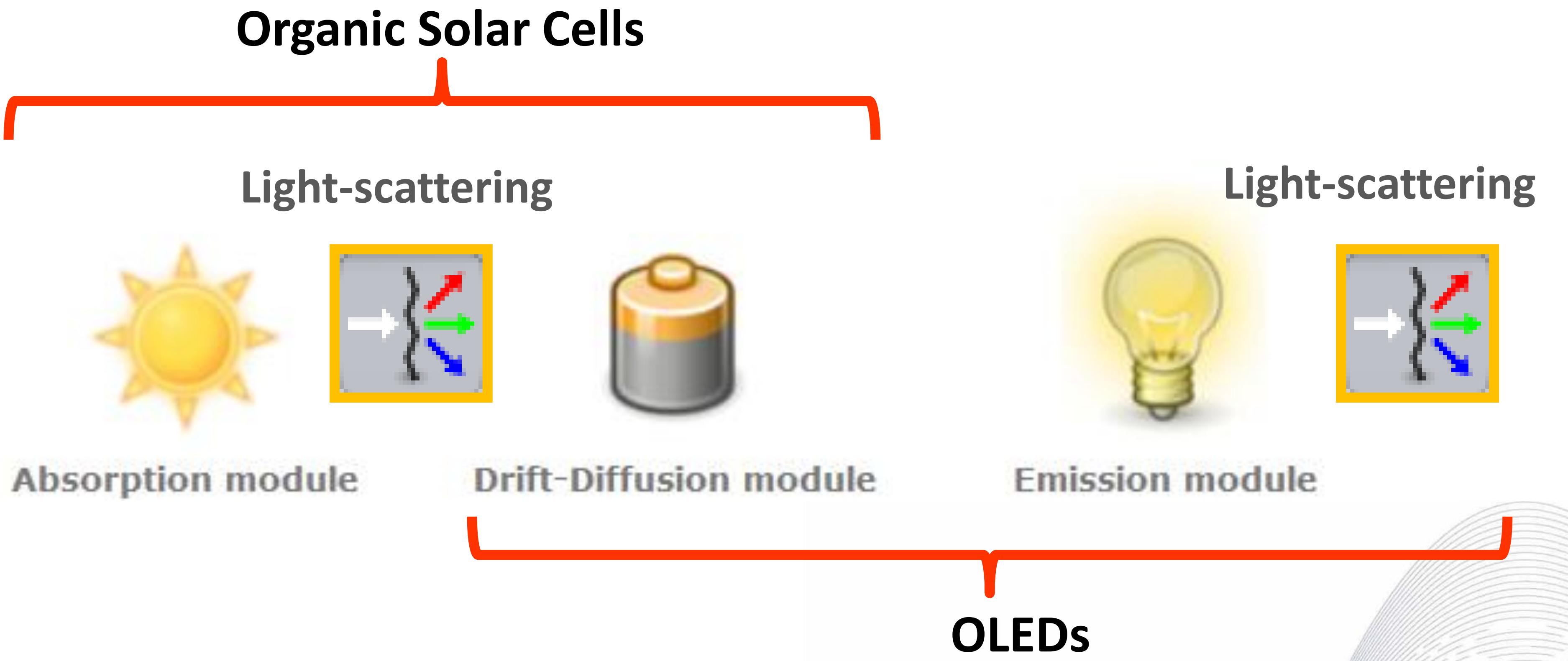
Clean room at
Fraunhofer Institute IMPS,
Dresden



100 individual OLEDs
by T. Beierlein, IBM Zurich

Setfos 4.0 Software Modules:

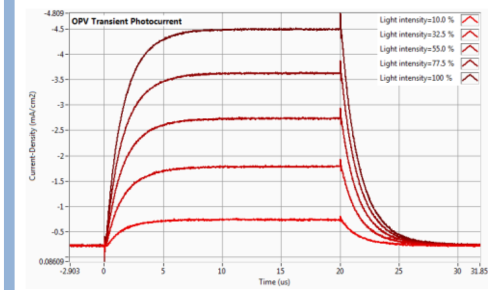
FLUXiM
www.fluxim.com



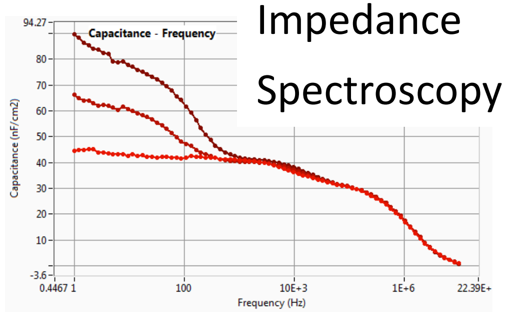
All-in-One!

www.fluxim.com

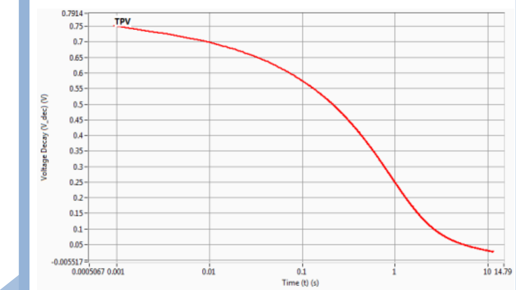
Transient Photocurrent



Impedance Spectroscopy



Transient Photovoltage



paios 2.0

The revolutionary platform for all-in-one characterization of solar cells

Capacitance-Voltage

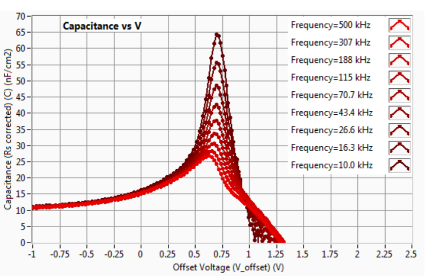
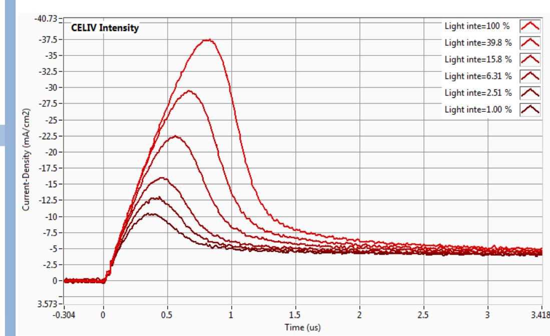
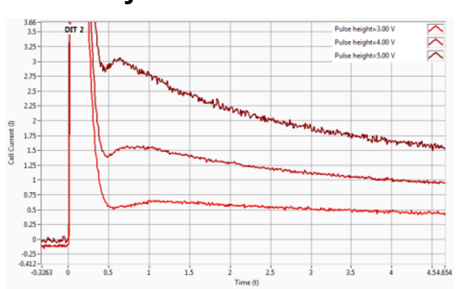


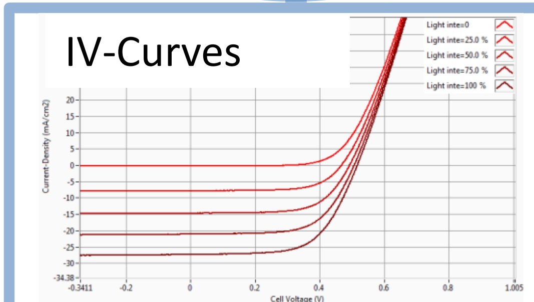
Photo-CELIV



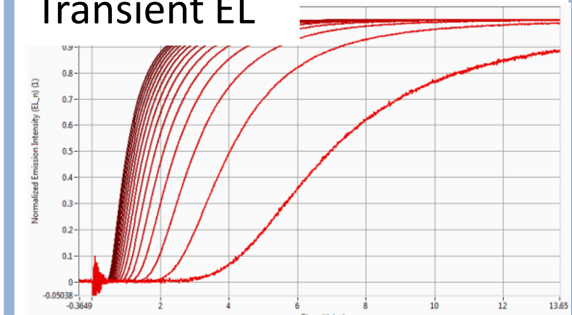
Dark Injection Transients



IV-Curves

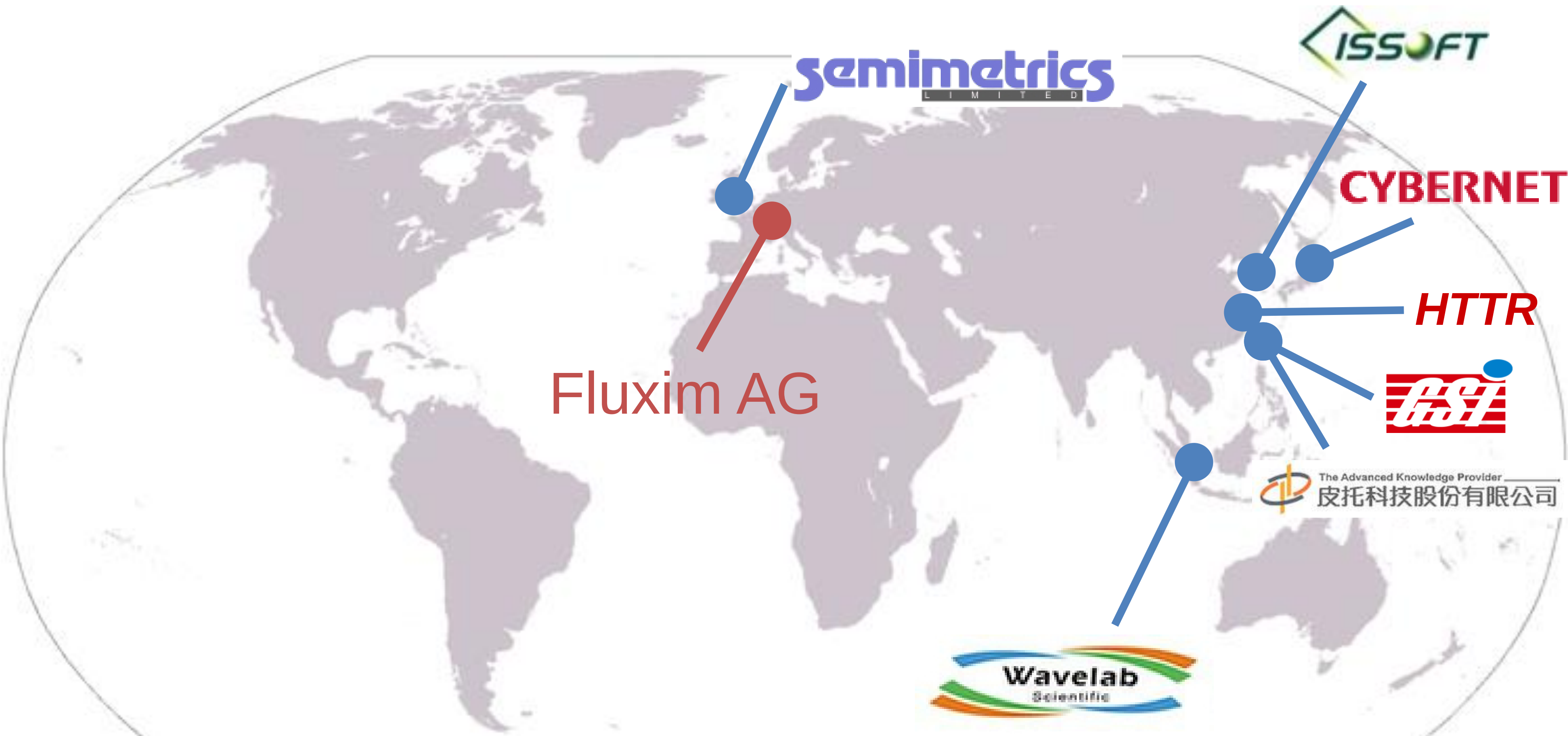


Transient EL



Worldwide partners & customers

FLUXiM
www.fluxim.com

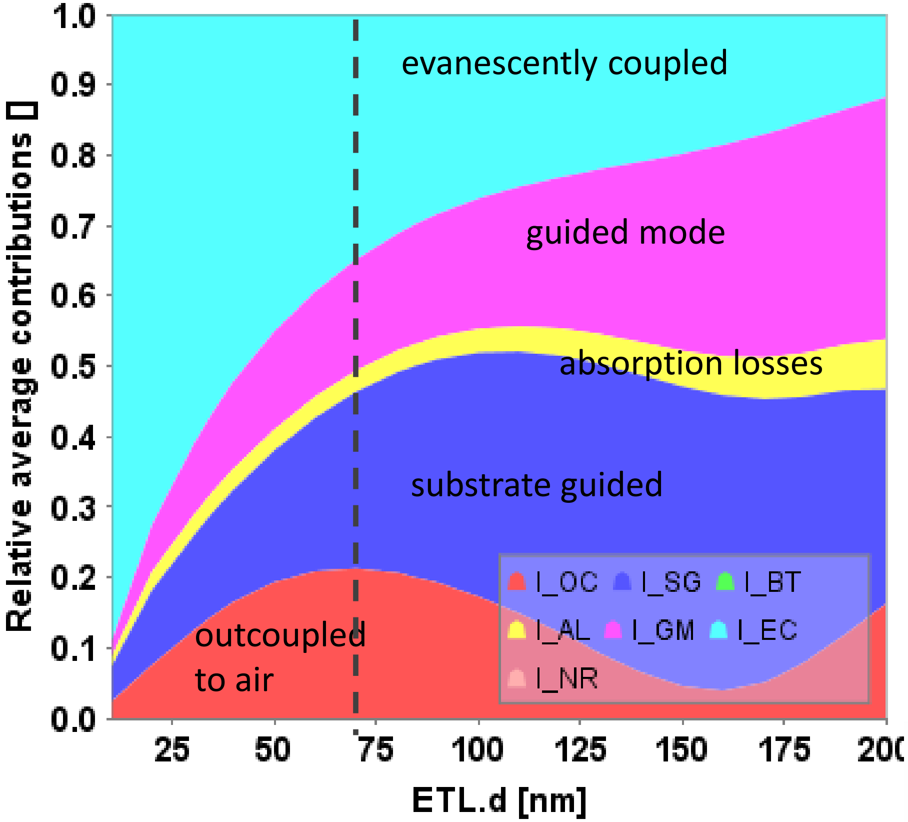


Key customers:

Novaled, BASF, Merck, Holst Centre, Fraunhofer, Dupont Displays, Samsung Display/SAIT, LG Display, LG Chem

OLED Light Outcoupling Challenge

FLUXiM
www.fluxim.com

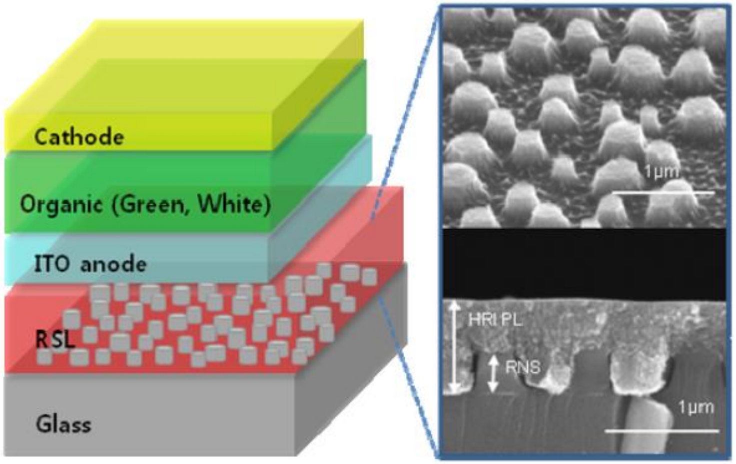


- Direct Emission (only ~20%!)
- Guided Modes inside the organic layers (~20%)
- Substrate Guided Modes (~25%)
- Evanescent modes (not capable of propagation, e.g. surface plasmons at metallic electrodes) (~25%)

Most of the internally emitted light is trapped inside the OLED!
Extra outcoupling tricks are needed to get more than 20% of the light!

Complex OLED Structures for Record Efficiencies

www.fluxim.com



- External light outcoupling (ELO) structures:
  - layers with scattering particles
  - microlense arrays
- High-index substrates
- Internal light outcoupling (ILO) structures:
  - nanostructures, textured interfaces & planarization layers

Random scattering layer
+ HRI planarization
ETRI, SID 2014

→ Simulation method must cope with such complex structures!

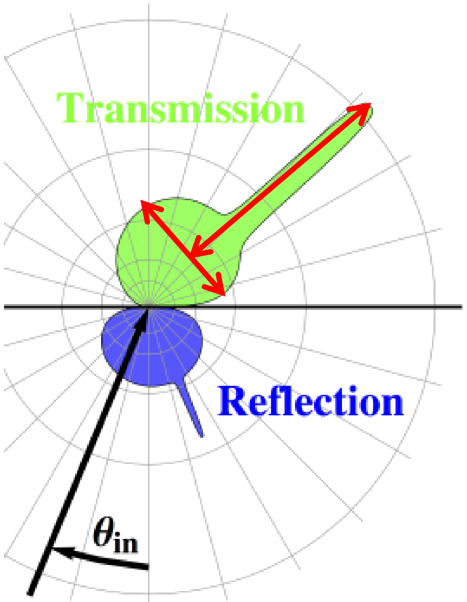
→ We may need to combine several out-coupling tricks for record efficiency.

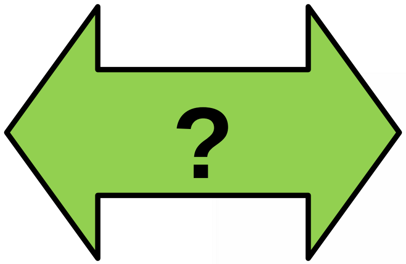
Design Challenges for Scattering OLEDs

FLUXiM
www.fluxim.com

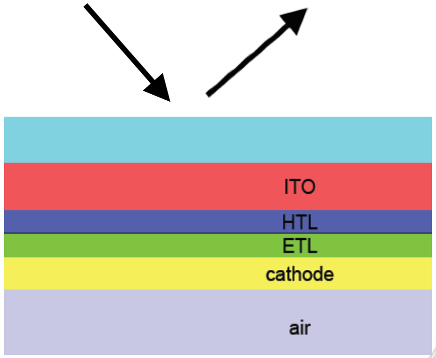
- **Scattering properties?**
- What is the ideal **haze**?
  (def. as ratio of scattered light)
- How **broad** should scattering be?

- **OLED stack properties?**
- Should the OLED be highly **reflective**?
- How about **absorption** in OLED layers?





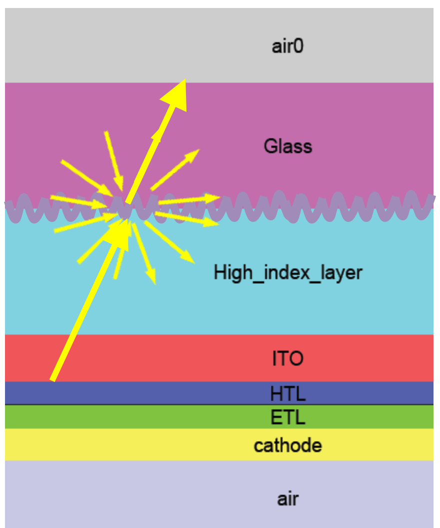
Combined optimization is necessary!

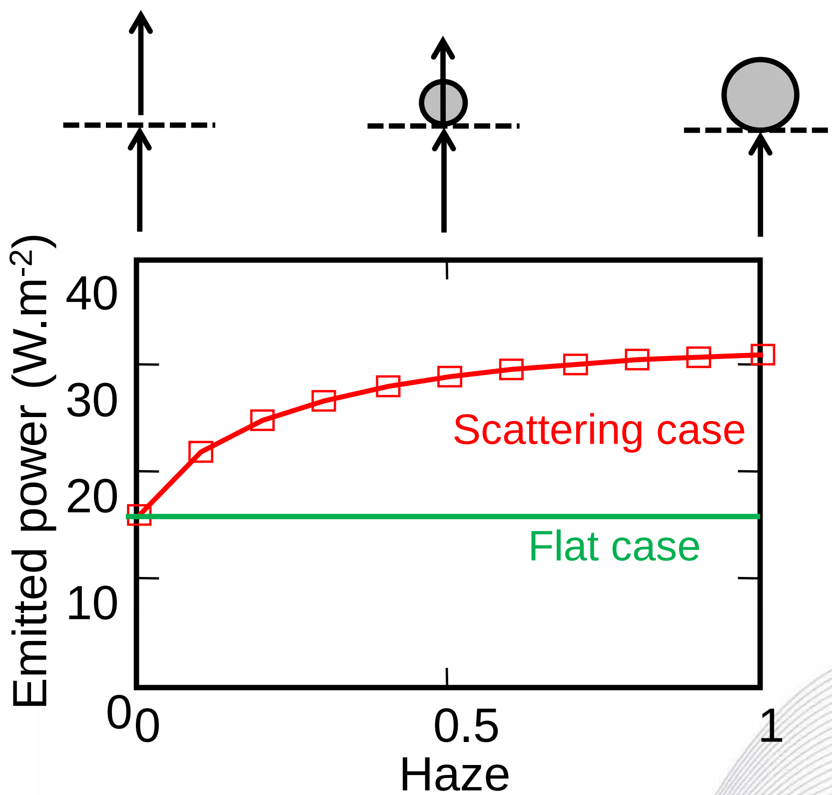


Impact of Haze on Emitted Power

How strong should scattering be? (amount of **haze**?)

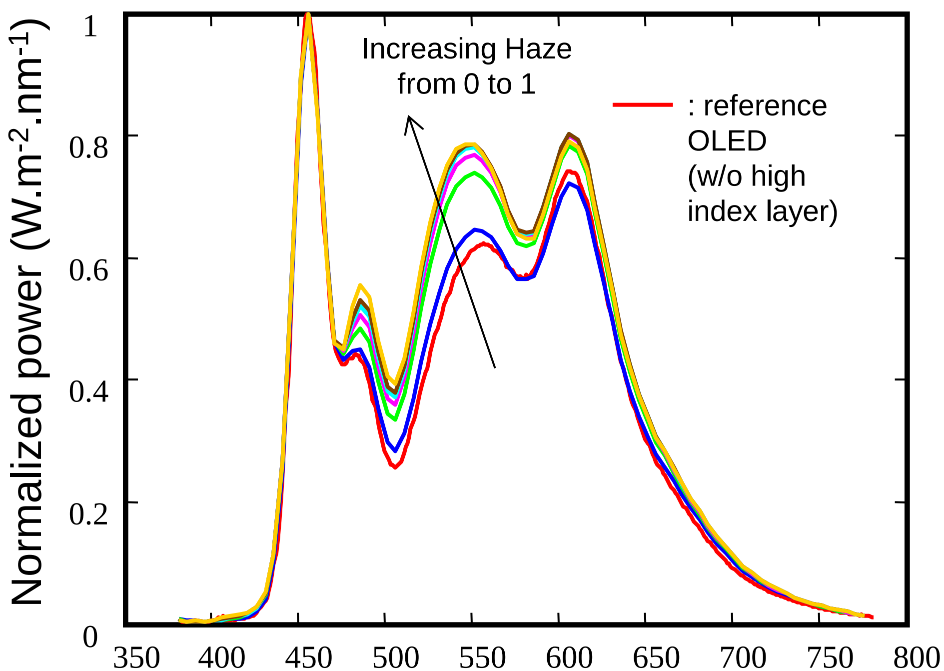
We assume that the scattered part of the light is a **Lambertian** function (cos(θ))



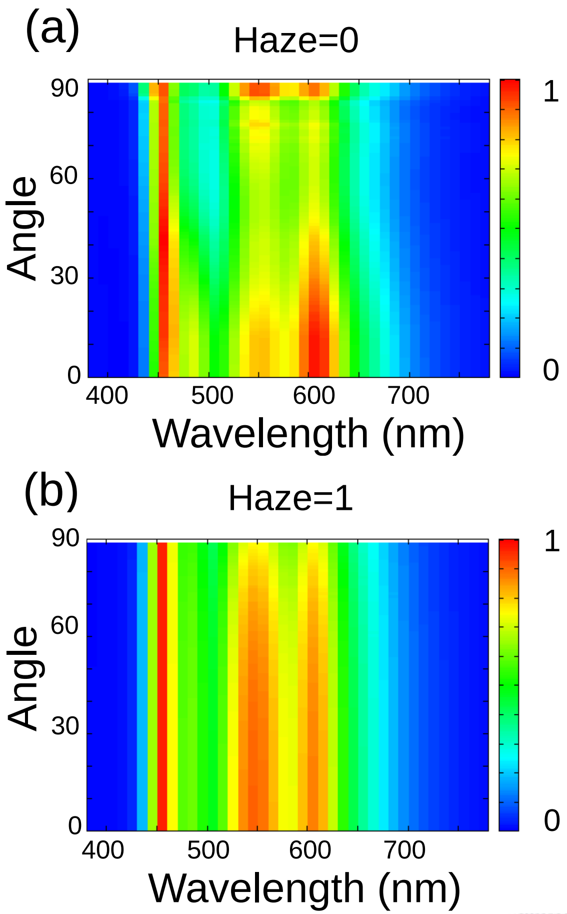


- The emitted power in air increases with the Haze.
- Even with 50% haze the emitted power almost doubles!

Impact of Haze on the Emitted Spectrum



Emission spectrum integrated in the hemisphere



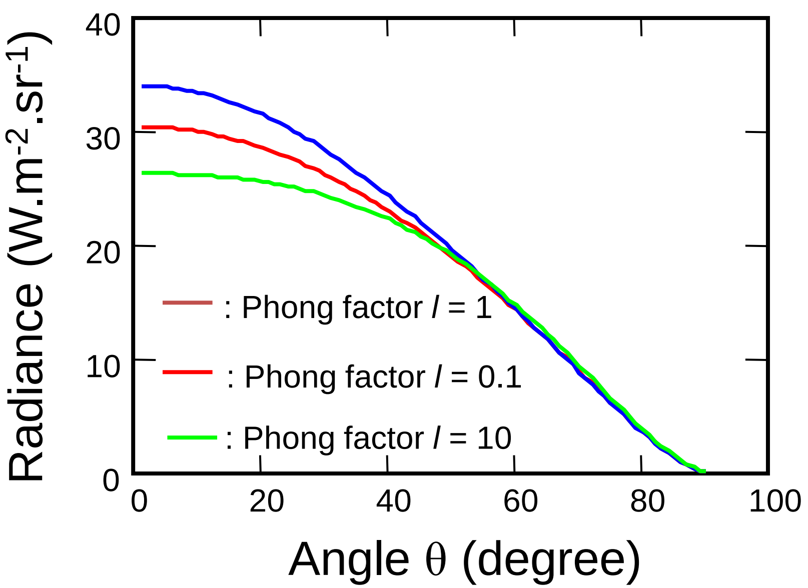
→ In order to achieve the target color, the OLED stack must be adjusted.

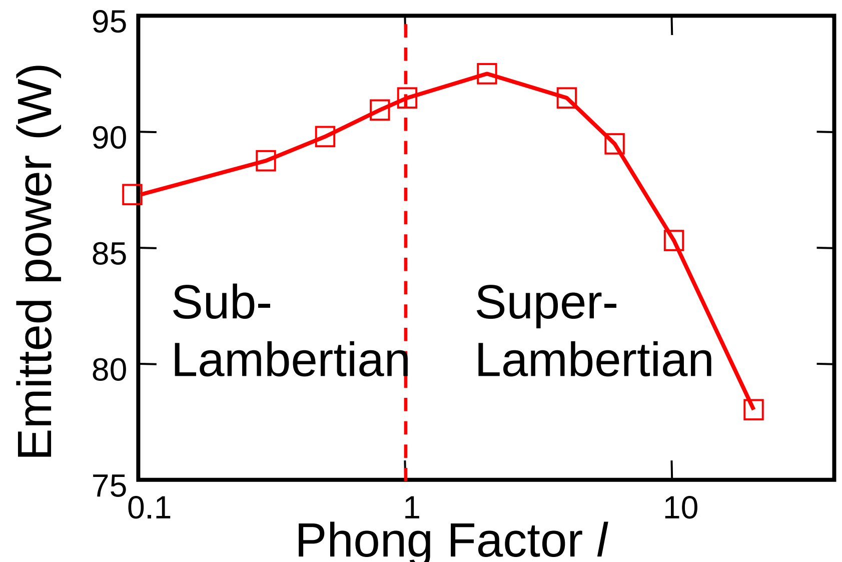
→ Scattering improves the angular color stability!

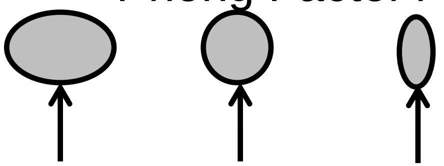
How strong should angular light scattering be?

FLUXiM
www.fluxim.com

(OLED with internal scattering)



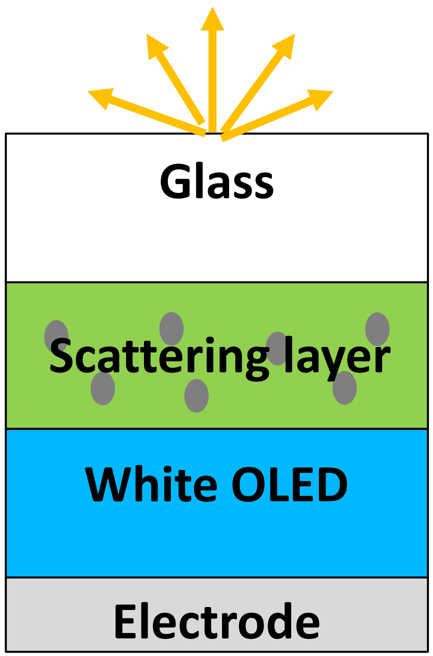


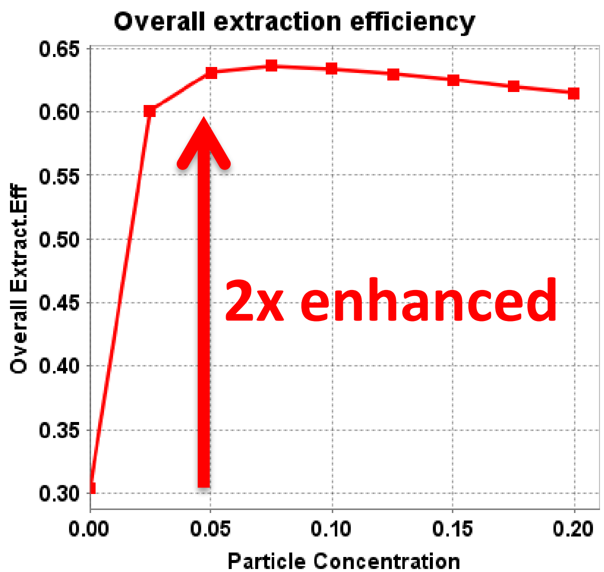


- Scattering function: $\cos^{l}(\theta)$
- A maximum out-coupling efficiency is achieved for a Phong factor $l > 1$
- Too broad scattering functions ($l < 1$) seem to have a negative impact on the outcoupling efficiency of the OLED.

Particle Scattering Films for OLEDs

Concentration dependence

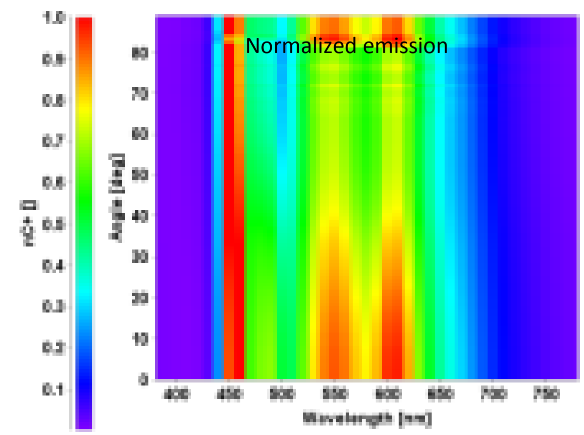




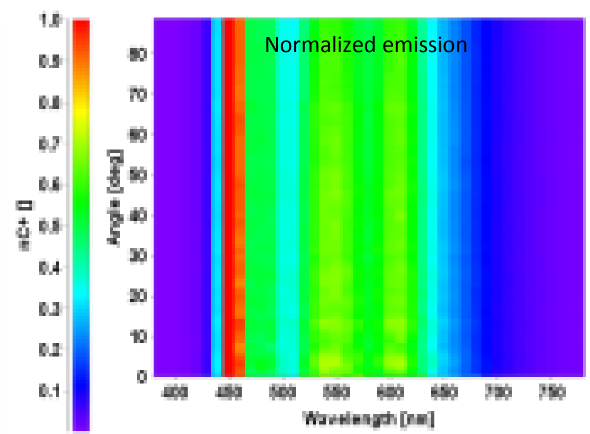
Simulations with SETFOS 4.1

Angular emission

Without particles



With particles c=7,5%

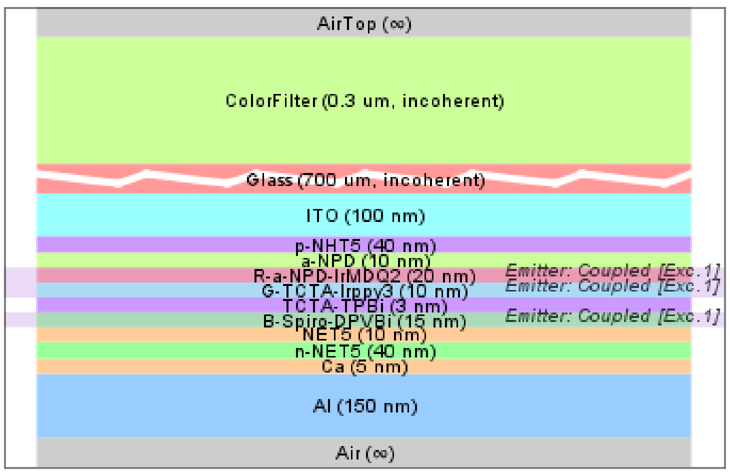


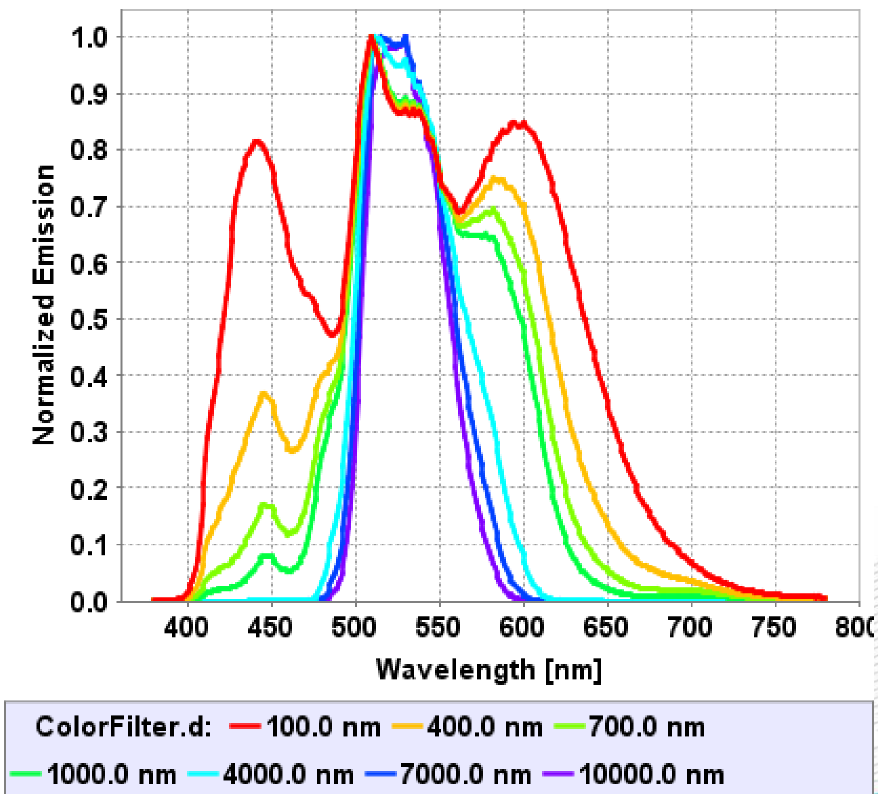
White OLEDs with Color Filter

(Arbitrary Layer Sequences)

Example: Thickness variation of green color filter

Layer structure



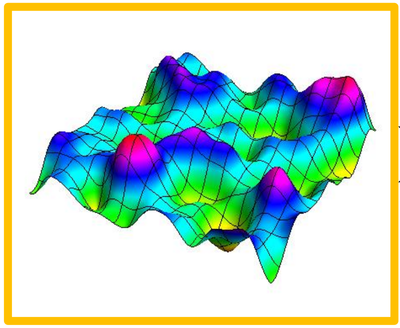


Hybrid model tackles thin & thick layers!

e.g. encapsulation layers

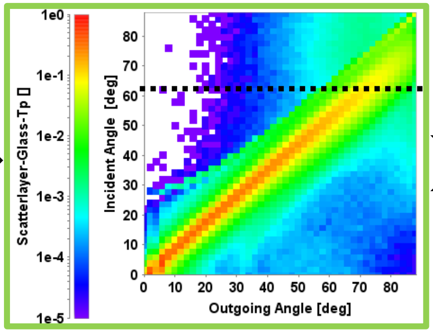
Summary of Simulation Workflow (OLED)

Scattering structure



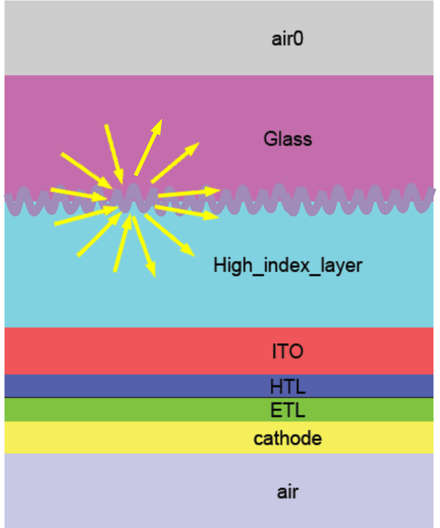
Examples:
textures,
particle scattering,
micro- and nano-structures

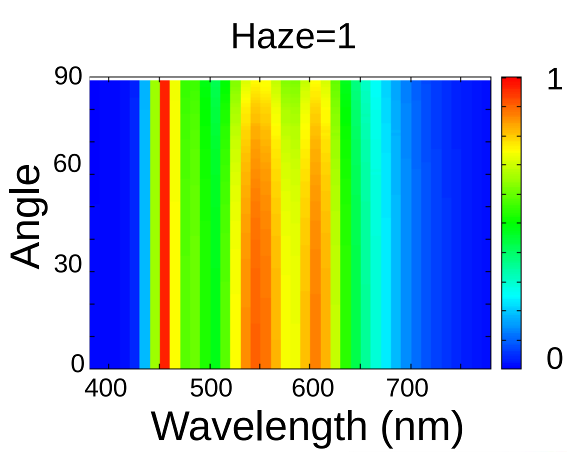
Bi-directional Scattering Function (BSDF)



Experiment or simulation

Design & optimize the OLED structure

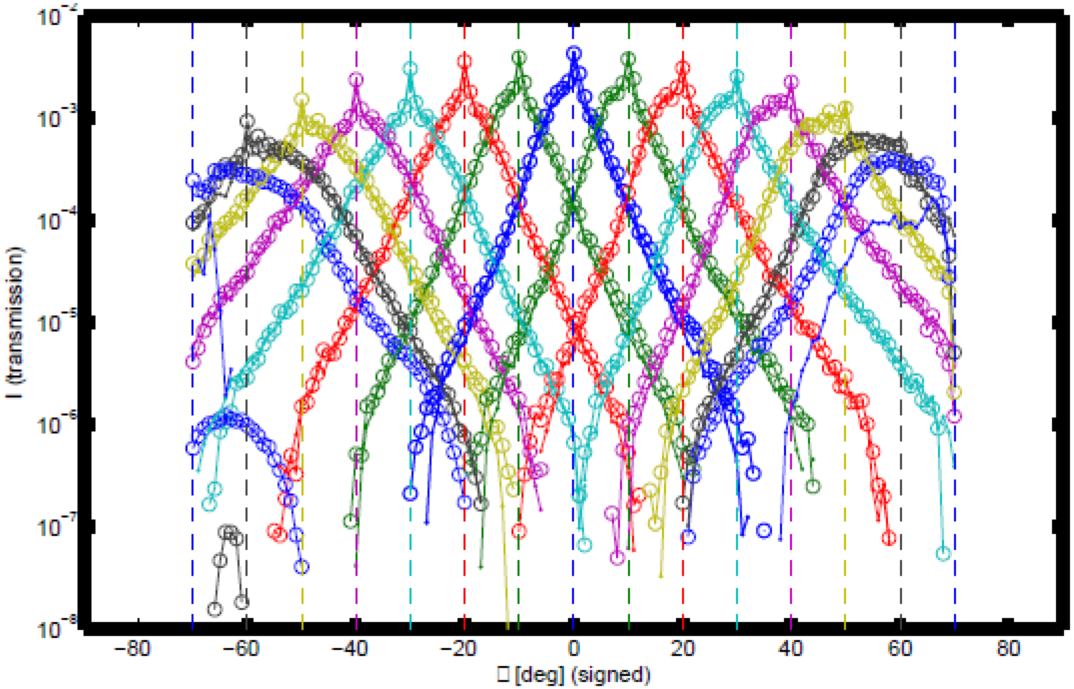




Measuring Scattering Properties

FLUXiM
www.fluxim.com

Angular transmission vs. incidence angle (BTDF)



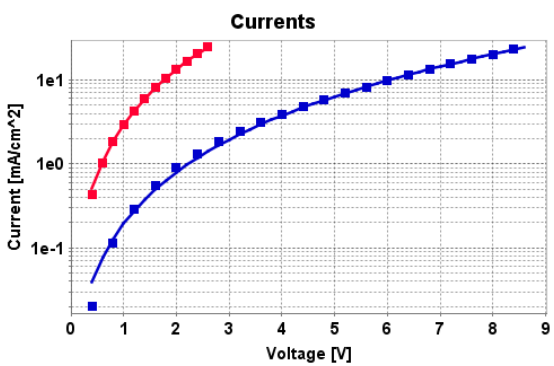
Kurt Pernstich, ZHAW

Zurich University of Applied Sciences
zhaw School of Engineering
ICP Institute of Computational Physics

OLED Challenges

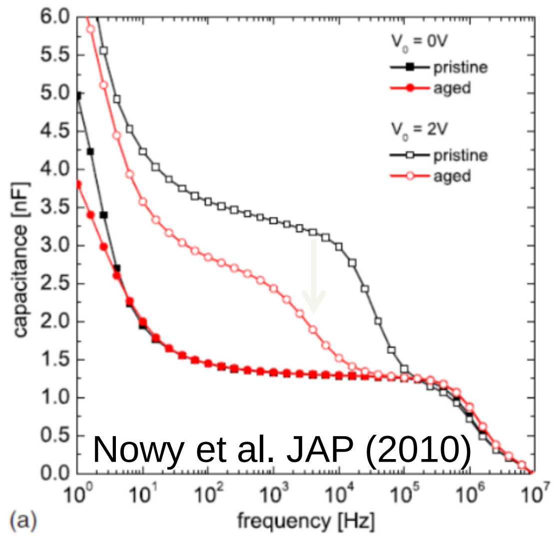
Efficiency → Lifetime → Up-scaling

Optimize EQE, Color...



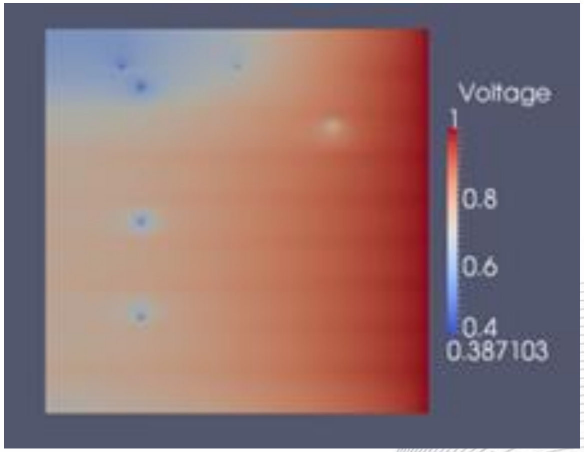
Extract charge mobility

Monitor & understand



C(f) for fresh & aged OLED

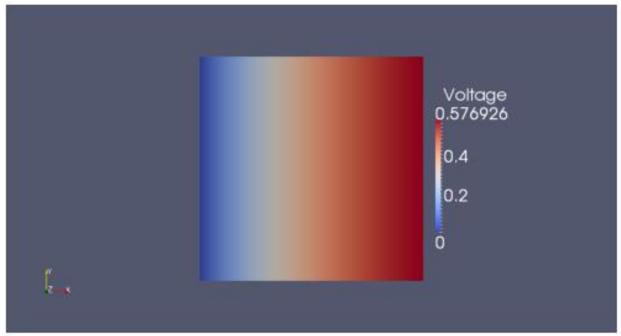
Design panels/displays, Minimize losses



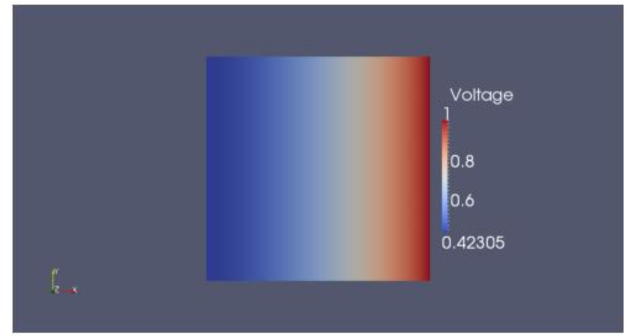
Simulated potential with metal grid & shunts

Large-area Electrode Simulations

- Reference OLED

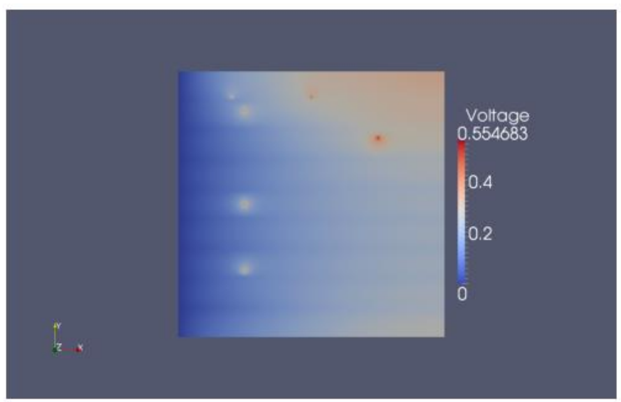


(a) 0 metal stripes, 0 shunts simulation: bottom layer voltage distribution

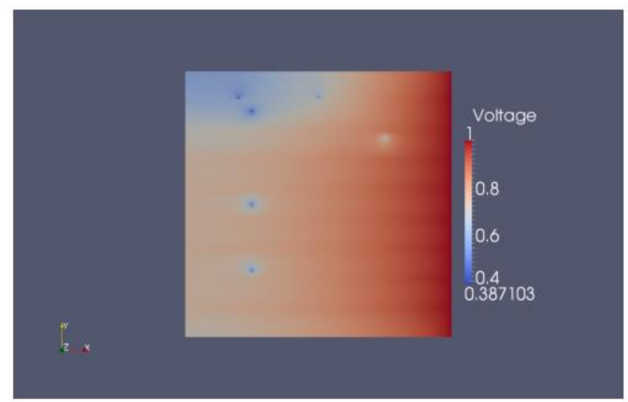


(b) 0 metal stripes, 0 shunts simulation: top layer voltage distrbution

- OLED with horizontal **metal grids** and random **shorts**



(e) 8 metal stripes, 6 shunts simulation: bottom layer voltage distribution



(f) 8 metal stripes, 6 shunts simulation: top layer voltage distribution

Conclusions

- We develop leading-edge simulation and characterization technology for large area (organic) electronics
- Mostly optical, electrical and thermal processes are investigated
- This technology accelerates R&D!

Acknowledgements

FLUXiM
www.fluxim.com

Fluxim

Stéphane Altazin

Clément Reynaud

Ursula Mayer

Lieven Penninck

ZHAW

Reto Knaack

Kevin Lapagna

Thomas Lanz

Kurt Pernstich

Fluxim AG, 2014

Financial Support:

EU-FP7 IM3OLED

EU-FP7 SUNFLOWER

CTI ScatOLED