OLED Light Extraction: ILEL vs. ELEL

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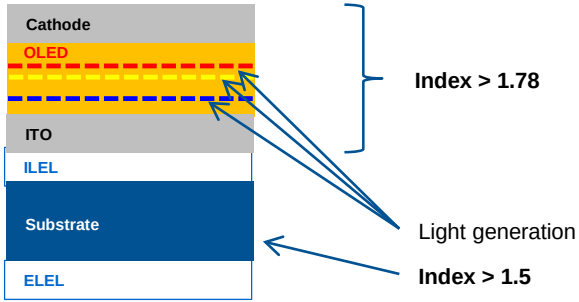
Outline

We report on our numerical assessment of the interaction between internal (close proximity to OLED stack) and external light extraction layers, which shows that the ultimate limit of optical extraction lies with the absorption of the structure.

- Problem Statement
- Method of investigation
- Tools
- Emission profile
- Results
  - Validation
  - Analytical model
  - ILEL – ELEL interaction
- Conclusions

Problem Formulation

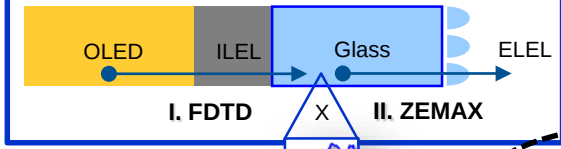
- OLED source



- Without any extraction layer
  - a lot of light (80%) is trapped or absorbed in high index medium and does not get out into the substrate
- ILEL
  - Redirect the light so that it has a chance to escape
  - Illumination case is easier – do not need to preserve images
- Still have to get the light out of the glass
  - ELEL?

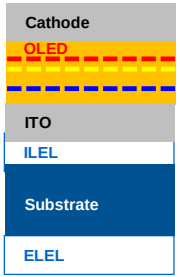
Can ELEL lead to better extraction of light out of OLED device?

Method: Multi-scale modeling approach

Schematic	Model	Step I	Step II
		FDTD	Ray-optics
 I. FDTD / Setfos	OLED (Base)	**Transmission (to-Air)** • Outcoupling Efficiency *into Air* • Power distribution (Setfos)	Not needed
 I. FDTD	OLED + ILEL		
 I. FDTD X II. ZEMAX	OLED + ELEL	**Transmission (into-Glass)** • Outcoupling Efficiency *into Glass* • Angular Profiles *in Glass* - Emission function - Scattering function	**Transmission (to-Air)** • Outcoupling Efficiency *into Air*
 I. FDTD X II. ZEMAX	OLED + ILEL + ELEL		

Tools

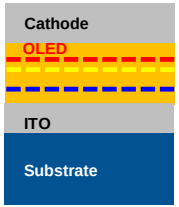
- Combine wave-optics
  - FDTD (essential for OLED design and ILEL)
  - Transfer Matrix (planar OLED, no scattering)
- Ray-tracing (practical for ELEL)

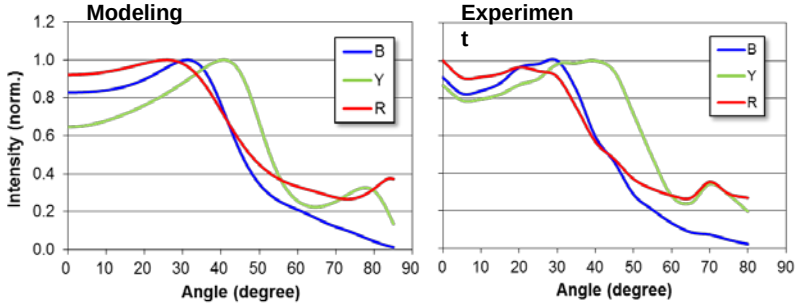


Method	Transfer Matrix (TM)	Finite Difference Time Domain (FDTD)	Ray-tracing
Dimension	1-D (OLED)	3-D (OLED+ILEL)	3-D (Substrate+ELEL)
S/W	Setfos (Swiss)	Lumerical (Canada)	Zemax (US)
Advantage	• Fast calculation speed • Power prediction inside OLED	• Sophisticated prediction of complex scattering geometry	• Fast calculation speed • Large features
Analysis	• Optical loss (Reflectance) • Emission profile • Extractable power ratio	• Haze & Transmission • Outcoupling Efficiency (Light extraction performance)	• Haze & Transmission • Outcoupling Efficiency (Light extraction performance)

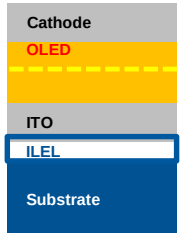
Emission profile matters

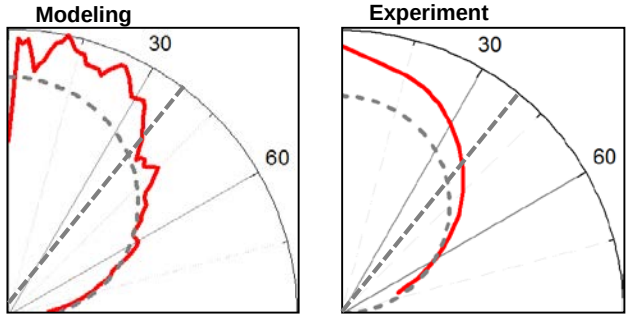
- Determines how much light is trapped





without light extraction substrates:
~20% extraction efficiency (into air) observed





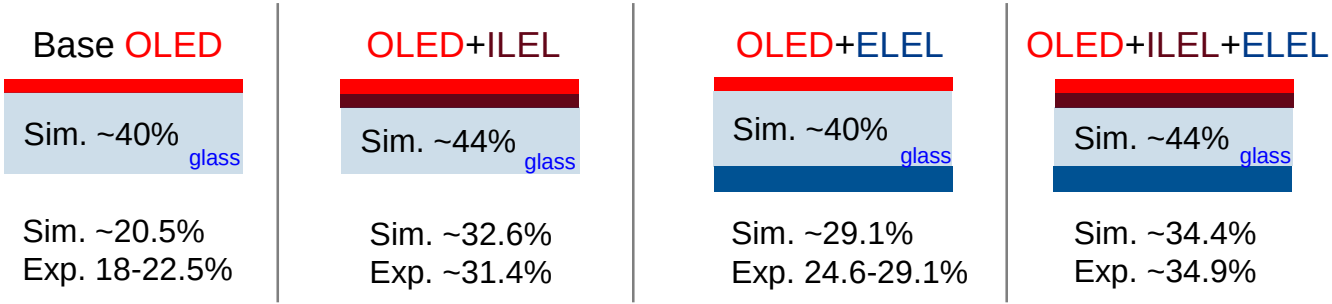
with ILEL substrates:
>1.5x extraction efficiency increase observed

Experiment & modeling results match reasonably well

In practice, the presence of ILEL in the OLED stack leads to a Lambertian angular distribution of the emitted light.

Multi-scale modeling validation (Single-stack device)

- Validation: Four OLED configurations with ILEL & ELEL



  - ILEL: ~44% into glass
  - Big benefit of ILEL in scattering light reflected from glass-air interface
  - Experiment and modeling shows that modeled ELEL does not help to increase the extraction significantly → need to find the best configuration of ILEL and ELEL.

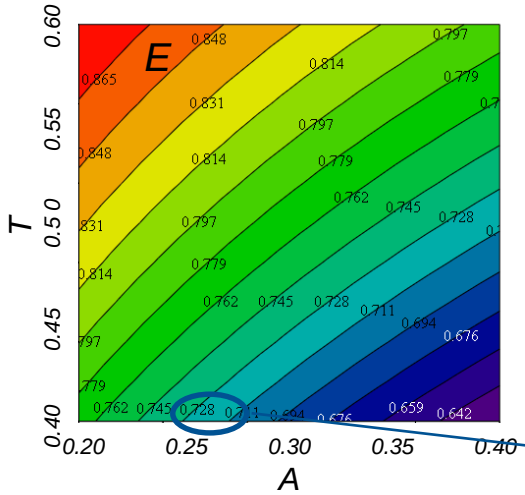
ILEL – ELEL interaction: Analytical model

- Existing OLED+ILEL design – can an ELEL be designed for an enhanced overall extraction?
- Simplified model (taking a hint from FDTD simulations)
  - Lambertian emission from OLED+ILEL
  - Lambertian scattering from OLED+ILEL, > 20% loss, no specular component

E* – *extraction from glass to air

T – transmission of ELEL for a Lambertian incident light

A - absorption of the OLED+ILEL



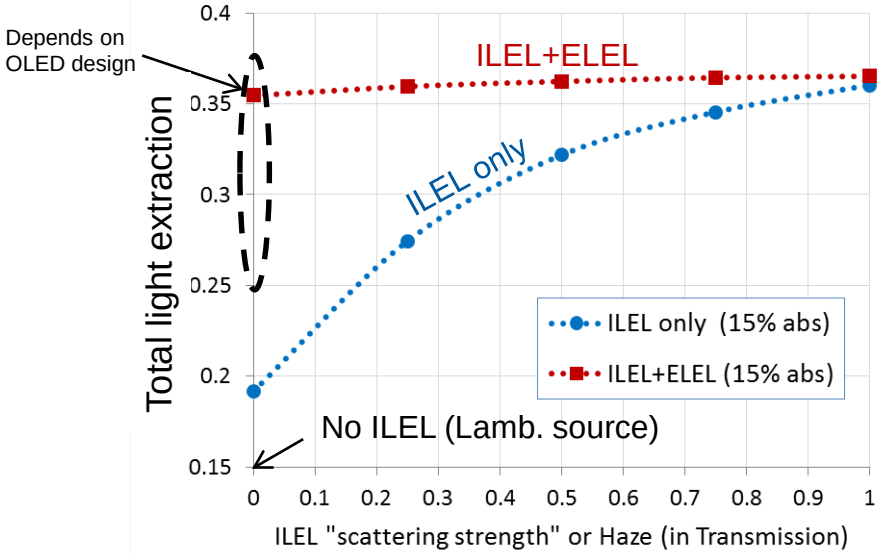
Sim. ~29.1%
Exp. 24.6-29.1%

40% x 73% = 29%

Need to Maximize *T* Minimize *A*

ILEL – ELEL interaction
Relative ILEL and ELEL contributions

- Two extractions:
  - From OLED into the substrate (using ILEL)
  - From glass substrate to air (using ELEL)



Total light extraction

$Extr_{OLED \rightarrow air} = Extr_{OLED \rightarrow substrate} \times Extr_{substrate \rightarrow air}$

Multiple ELEL designs modeled The best have

$Extr_{substrate \rightarrow air} \sim 0.8$

When ILEL is strong, impact of ELEL is incremental

Conclusion: ILEL – ELEL interaction

- Can ELEL lead to better extraction of light out of OLED device?
  - Did not find an effective ELEL to work with an essentially Lambertian source/reflector, which is a close approximation to the current OLED+ILEL design
  - ELEL less effective when ILEL is good
    - Maximal benefit limited by OLED+ILEL loss
  - Focus should be on:
    - Improvement of outcoupling from OLED to Substrate
    - Lowering OLED loss