

OLED-Based Display

Products: FullWAVE FDTD, LED Utility, DiffractMOD
RCWA, LightTools

Applications: Displays and Imaging, Solid-State
Lighting

Introduction

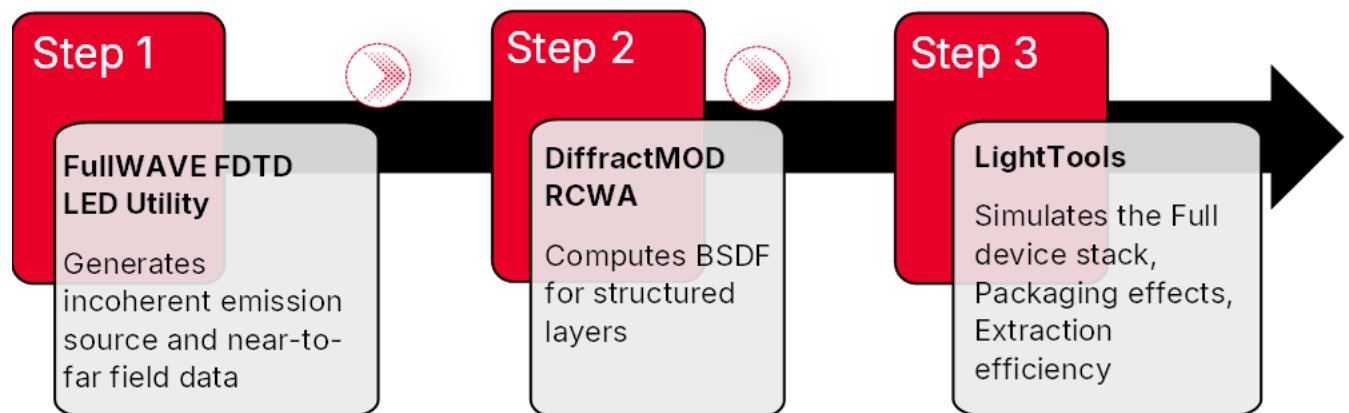
Stringent power constraints required the development of an OLED device with a nanoscale, moth-eye pattern on the glass-to-air interface to maximize light extraction efficiency. OLED devices are typically simulated with ray tracing tools **LightTools**, which cannot include the subwavelength feature sizes of a moth-eye pattern. The RSoft **DiffractionMOD RCWA** and **FullWAVE FDTD** tools are ideal solutions for this design challenge.

OLED efficiency is fundamentally limited by light trapping due to refractive index mismatches, leading to significant losses in substrate and waveguided modes.

Flow Description

A paper[1] presents a mixed-level optical simulation methodology for OLED design that combines rigorous electromagnetic (EM) solvers (FDTD, RCWA) with Monte Carlo ray tracing to accurately model light extraction and device performance across multiple length scales.

The approach enables comprehensive and efficient simulation of both nanostructured device layers and macroscopic packaging effects, overcoming the limitations of using either wave optics or ray optics independently.



Validation Example

A bottom-emitting OLED structure [2] was simulated to validate the methodology.

In this paper, the study is conducted on the optimal position of emission layer (represented by an orange line in Figure 1) inside the organic layer.

However, results from a series of coherent simulations, each with a different polarization and relative point source position, can be combined to produce an incoherent output. This output describes the intensity distribution at a surface (Figure 3), which can be converted into source data for ray tracing techniques. FullWAVE FDTD based **RSoft LED Utility**, was used to model the incoherent source.

Step 2: Compute Optical Properties for Structured Layers

A Bidirectional Scattering Distribution Function (BSDF) is used to characterize the scattering properties from the surface of an arbitrary structure. Though its definition may vary, a BSDF describes the radiance of scattered light (angularly dependent) as a function of incident angle, wavelength, and polarization.

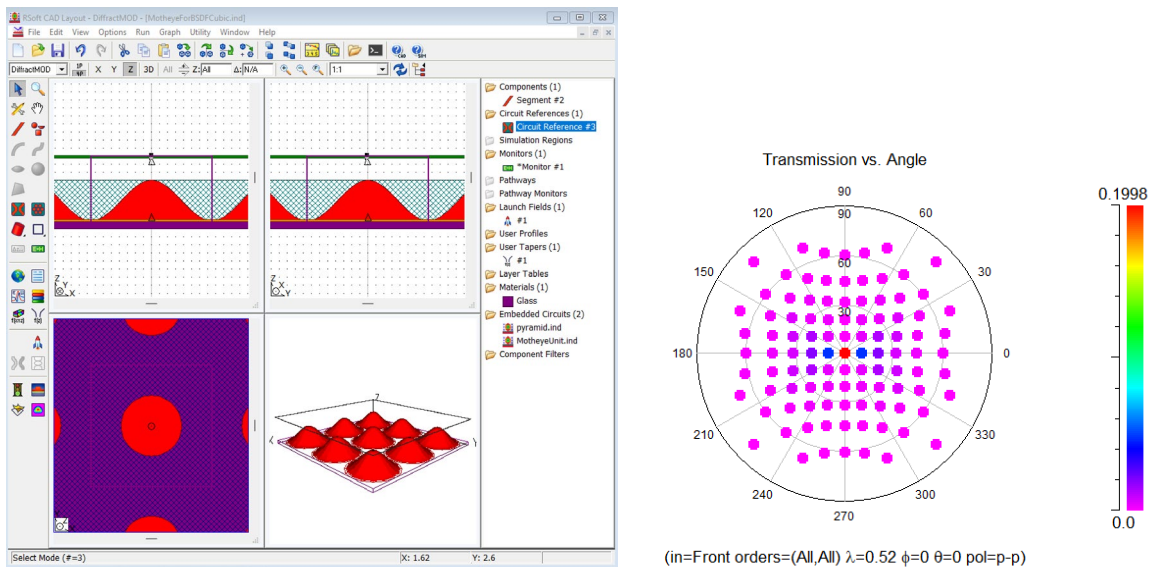


Figure 4. Moth's eye structure designed in RSoft CAD and the angular representation of the transmission order at normal incidence and 520 nm.

A BSDF can either be measured experimentally or calculated through the use of rigorous EM techniques. Ray tracing (LightTools) can use a BSDF at a surface to represent some underlying structure which could not otherwise be simulated under the geometric optics approximations. BSDF Utility was used to generate the required BSDF, the algorithm to compute those data was DiffractMOD RCWA based.

Step 3: Data Transfer to Ray Tracing Software

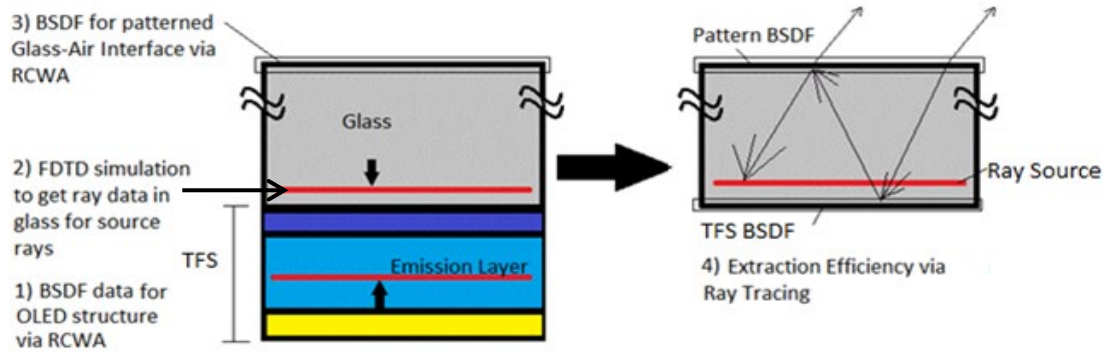


Figure 5. Schematic of the combined EM (RCWA+FDTD) and ray tracing based simulations. The simplified OLED structure is shown on the left, and the structure used in ray tracing is shown on the right.

The complexity of the Thin Film Stack (TFS) is first reduced to two simple surface properties for use within ray tracing, shown in Figure 5 (right). The first property describes the rays emitted from the TFS as calculated in Step 1. The second property describes how rays, incident from other parts of the structure, will be scattered from the surface of the TFS. This information is contained within BSRF. It can be flat surface or textured as shown in Step 2.

Step 4: Simulate the Full Device Stack and Performance Analysis.

As shown in Figure 6, having now the full stack defined in LightTools, monitors are added on the design to compute the out-coupling light of the OLED.

The validation of the mixed EM and ray tracing approach is conducted using a flat surface in between glass and air.

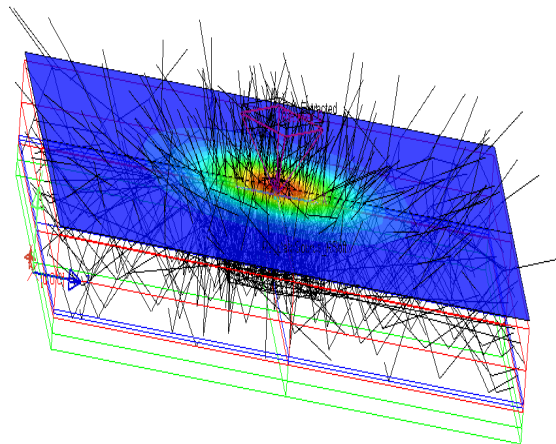


Figure 6. Visualization of the full stack in LightTools. The monitor at the top enables the visualization of the out-coupling light from the OLED cavity.

On the Figure 7, we can notice the good agreements in between the simulation (green line) and the literature [2] and [3] with a maximum out-coupling into air of ~21% occurring for a 'd' of 60 to 70nm.

From the FDTD simulation results (blue line) that the maximum coupling into the glass substrate was ~55% and occurred for a cathode-EML separation, 'd', of 100nm, meaning that ~30% of light remains trapped into the glass.

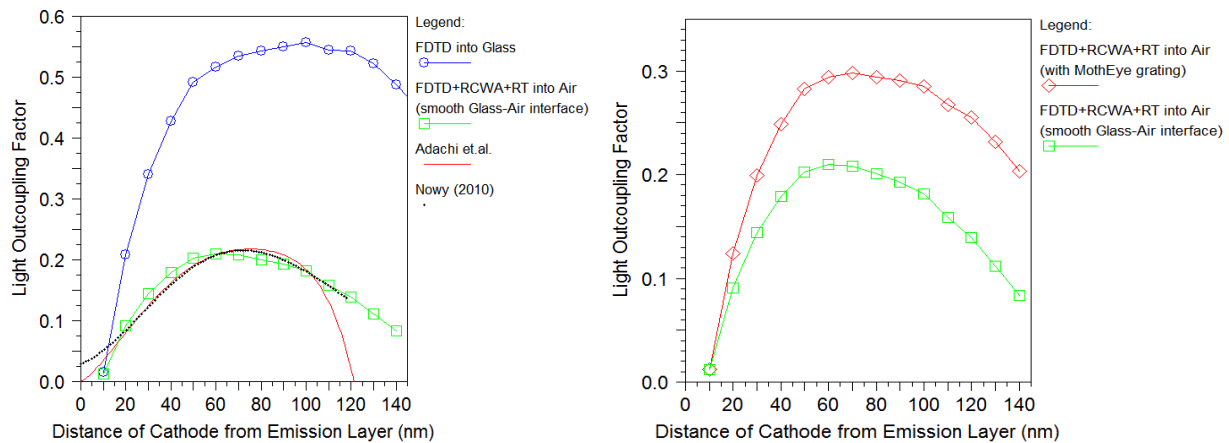


Figure 7. Performance of the flat cavity on the left versus literature and on the right the simulated performance adding the moth's eye textured surface.

Adding the moth's eye structure at the top of the OLED package improves significantly the light extraction as it is shown on the right part of Figure 7.

Conclusion

A mixed EM and ray tracing simulation methodology provides a powerful solution for modeling OLED devices across multiple scales.

This approach:

- Accurately predicts device performance
- Enables efficient design exploration
- Bridges nano-scale physics with system-level behavior

The demonstrated results show that interface engineering combined with accurate multi-scale modeling can significantly enhance OLED efficiency, with improvements exceeding 40% in extraction efficiency for optimized structures.

Example Files

Supporting Files for Application Note: OLED-design

References

- [1] Bahl, M., Zhou G-R, Heller E., et al. , Proc. SPIE 9190, Thirteenth International Conference on Solid State Lighting, 919009 (18 Sept 2014); <https://doi.org/10.1117/12.2061089>
- [2] Adachi, C., Baldo, M.A., Thompson, M.E, and Forrest, S.R., J. Appl. Phys. 90, 5048 (2001).
- [3] Nowy, S., "Understanding losses in OLEDs: optical device simulation and electrical characterization using impedance spectroscopy", Dissertation, 73 (2010)

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