THE EFFECTS OF LIGHT SCATTERING ON OLED EFFICIENCY

Andre Antoine and Bjorn Lussem

Kent State University, Department of Physics, Ronald E. McNair Post-Baccalaureate Achievement Program

Introduction

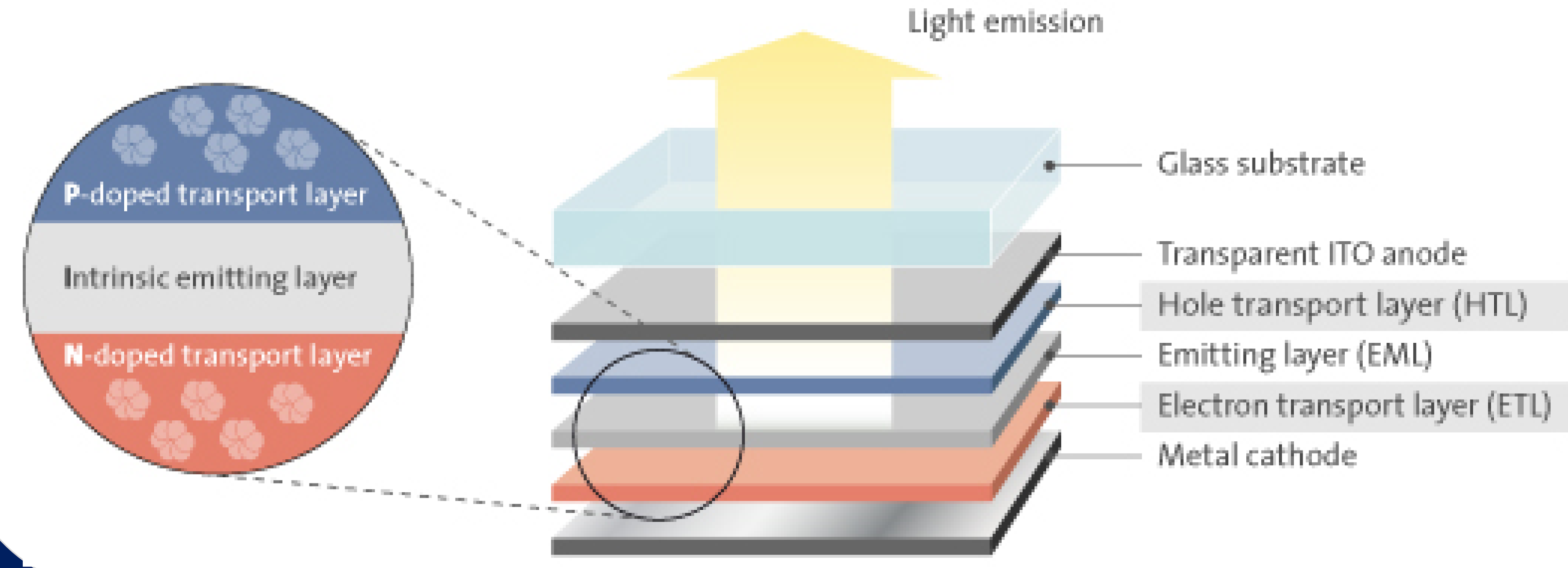
OLED outcoupling efficiency is limited by several factors, one major fact or is the limitation caused by internal reflection of light with the interface between organic layers including the anode and glass substrate. We approa ch this problem by adding a fairly exotic material to the OLED setup, whic h strongly scatters light. We expect the scattering to lower total internal ref lection and increase outcoupling efficiency. We compare the out coupling efficiency of the control OLEDs and the OLEDs with the scattering layer.

•OLEDs can reach 15-20 times more efficiency than incandescent lighting systems.
•Of all the energy consumed in the United States (U.S.), approximately 25% is consumed by lighting.
•Better efficiency in OLEDs brings high economic and ecological benefits.
•Tang and Vanslyke invented the first OLED in 1987 at Kodak labs.

Literature Review

THE PIN OLED STRUCTURE

Pin OLEDs architectures have the most promising efficiency. The pin OLED consists of at least five organic layers between a transparent indium tin oxide (ITO) anode and an aluminum cathode. From bottom to top these layers are a p-doped hole injection layer (HTL), an electron blocking layer (EBL), an emission layer (EML), a hole blocking layer (HBL), and an n-doped electron transport layer (ETL). Electrons are injected through the Al cathode and holes are injected into the ITO anode. These electrons and holes are driven through their respective transport layers until they drift to the middle and recombine. The EBL is designed specifically to stop electrons from passing the EML into the HTL layer, while the HBL is designed to stop holes from passing the EML into the ETL. If either case was to occur, there would be a disproportionate amount of recombination outside of the EML thereby lower the efficiency of an OLED. In the emission layer, excitons are formed by the recombination of electrons and holes. Light is finally produced by the radiative decay of excitons.



EXTERNAL QUANTUM EFFICIENCY

The external quantum efficiency (EQE) is one of the most important figure of merit of OLEDs; it is defined as the ratio of photons outcoupled from the device to the electrons generated within the device. The best OLEDs have an EQE of about 25%. The most severe factor that limits the EQE is the outcoupling efficiency ξ , which is the ratio of emitted photons to the total number of photons generated inside the OLED cavity. Although almost all charge carriers injected in to the OLED form an exciton, which decays and emits a photon, most of these photons are trapped inside the OLED. Therefore, most OLED research currently focusses on clarifying the reasons for the low outcoupling efficiency and on developing new approaches to increase it.

Methods

THERMAL EVAPORTATION PROCESS

- We use a thermal evaporation process performed in an ultra-high vacuum(UHV) environment at a base pressure of 10^{-8} mbar.
- The organic molecules are placed into crucibles at the bottom of the chamber, heated by Cu coil.
- The thicknesses of the HBL and EBL is set at 10nm. The HTL is set to 60nm, the EML set to 20nm and the Al cathode set to 100nm.
- The ETL, along with the scattering layer (12H-Benzo[b]phenoxazine) is varied at differing thicknesses: 40, 60, 80 and 100 nm for the ETL and 0, 20 60 and 100nm for the 12H-B.
- Evaporation rate is kept between 0.3~0.4 Å/s save the EML and cathode which were 1.0 Å/s.
- After processing the run we measure efficiency with a photodiode by stepping the voltage by 0.1V to 4.0V on a forward backward sweep.
- The data obtained allows s to calculate relevant attributes such as EQE(η_{ext}), radiant power (flux) (Φ_E) [W], luminous flux(Φ_V)[lm], luminous efficiency(η_p), and luminance(L_V) [cd*m^{-2}].
- We later use an integrating sphere, allowing us to measure some characteristics directly.
- The radiant flux Φ_E is defined by integration of the spectral radiant flux over the range of wavelengths.
- Since we cannot account for a continuous spectrum of wavelength,, we use a function defined by:

$$\Phi_E\ [\mathrm{W}] = \int \Phi_E(\lambda)d\lambda \approx \sum \Phi_E(\lambda)\Delta\lambda\ (2)$$

where Φ_E is a function of λ, the wavelength. [16] Φ_V is given by:$\Phi_E\ [\mathrm{W}] = \int \Phi_E(\lambda)d\lambda \approx \sum \Phi_E(\lambda)\Delta\lambda \#(2)$
where Φ_E is a function of λ, the wavelength. Φ_V is given by:

$$\Phi_V\ [\mathrm{lm}] = \mathrm{K_m} \int_{\lambda=380}^{\lambda=830} \Phi_E(\lambda)V(\lambda)d\lambda\ \#(3)$$

where $\mathrm{K_m}$ = 683 [lm/W] and V(λ) is a function of wavelength describing the spectral response of the human eye. For our measurements, L_V, the intensity of light emitted from a surface per unit area is given by:

$$\begin{aligned}\Phi_V &= \int_0^{2\pi}\int_0^{\pi/2} \mathrm{L}_V A cos\theta sin\theta d\theta d\phi \\ &= 2\pi \mathrm{L}_V A \int_0^{\pi/2} cos\theta sin\theta d\theta \\ &= \pi \mathrm{L}_V A \int_0^{\pi/2} sin2\theta d\theta \\ &= \pi \mathrm{L}_V A[-cos2\theta/2]_0^{\pi/2} \\ &= \pi \mathrm{L}_V A\end{aligned}$$

$$\mathrm{L}_V \left[\frac{\mathrm{cd}}{\mathrm{m}^2}\right] = \frac{\Phi}{V}{}_A\ \#(4)$$

where A is the area of the OLED. We can attain η_p, the ratio of luminous flux emitted by the device and the power consumed, using our data as follows:

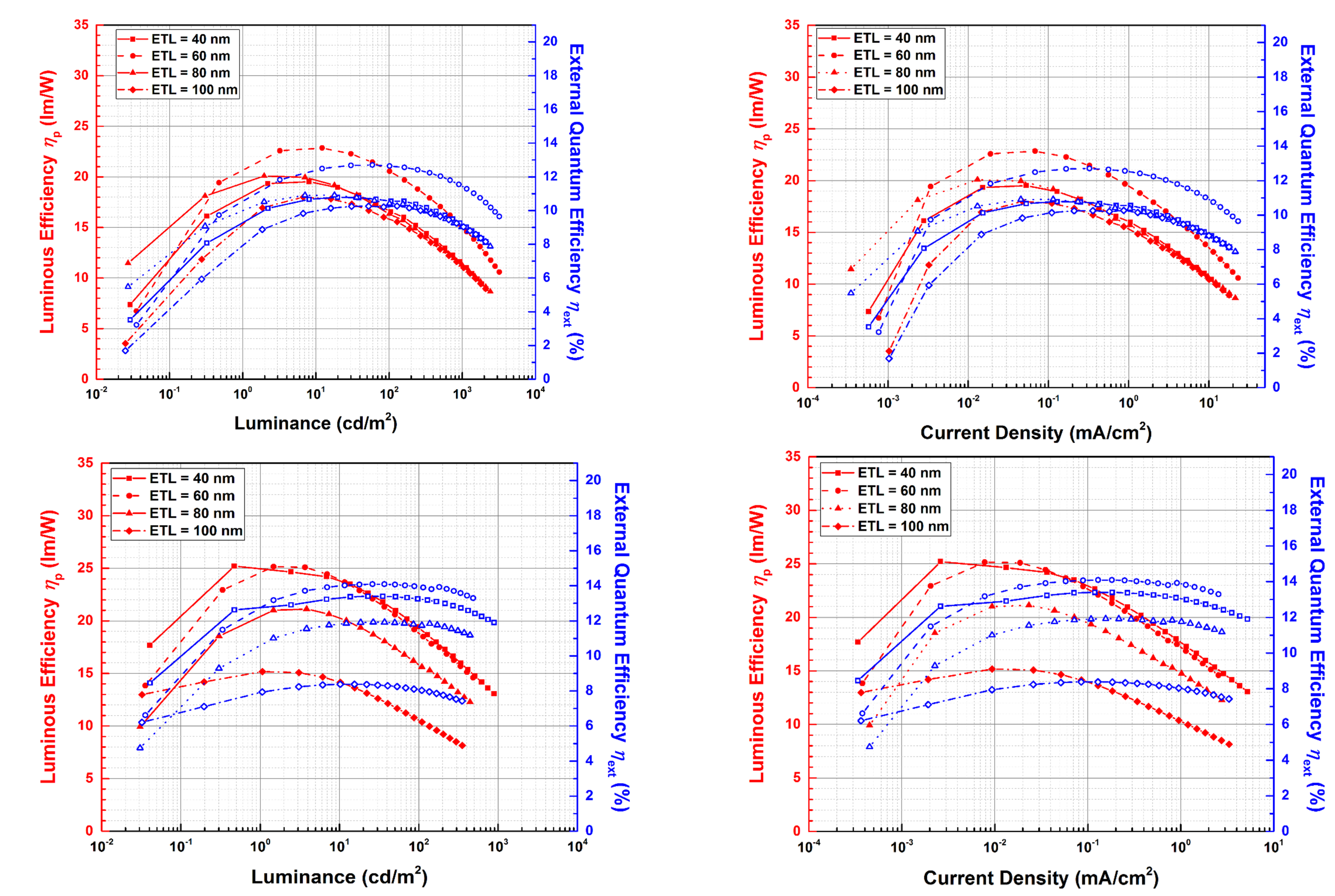
$$\eta_p \left[\frac{\mathrm{lm}}{\mathrm{W}}\right] = \frac{\Phi_V}{I_{OLED}V}$$

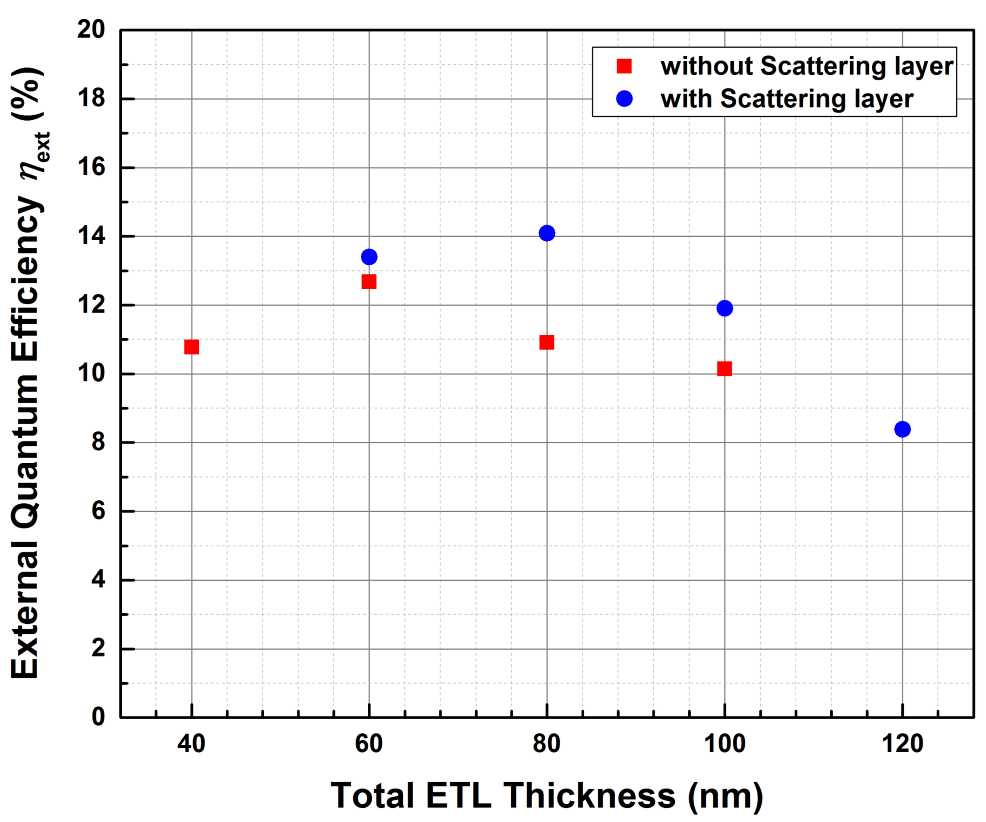
where I_{OLED} is the current through the OLED device and V being the input voltage.
To measure η_{ext} with our collected data we perform calculations by the given function:

$$\eta_{ext}\ [\%] = \frac{\int \frac{\lambda}{hc}\Phi_E(\lambda)d\lambda}{\frac{I_{OLED}}{q}} \times 100 = \frac{\#\text{ of photons/sec}}{\#\text{ of electrons/sec}} \#(5)$$

where λ is a given wavelength on the electromagnetic spectrum, h is Planck's constant c is the speed of light in a vacuum, and q is the elementary charge.

Results





Conclusion

When considering the addition of the scattering layer, we see a significant decrease in luminance as function of anode voltage. The same can be said for current density. Conversely, there is an increase in EQE and luminous efficiency as a function of luminance. The same increase trend is seen for EQE and luminous efficiency as a function of current density. This agrees with the slight increase observed when the 20nm scattering layer is added for a total ETL thickness of 80nm.

The observed trends indicate a slight increase in efficiency for an additional scattering layer of 20nm. However, the increase is small (about 1-2% in EQE), which is most likely within the usual scattering of experimental data. Furthermore, thicker scattering layers (40nm and above) show severely degraded charge transport properties and almost no light emission. More experiments must be performed to clarify the influence of a thin scattering layer on the efficiency of OLEDs. Structural characterization of the scattering layers, e.g. by scanning electron microscopy, is essential. Furthermore, modelling by FTDT methods will clarify the influence of scattering on the OLED behavior in more detail.

References

S. R. Forrest, "Prof. Stephen Forrest, William Gould Dow Professor of Electrical Engineering," EECS Univer sity of Michigan, 2012. [Online]. Available: https://www.youtube.com/watch?v=boD-SS1pnNQ. [Acces sed: 07-Jan-2016].

B. Lussem, M. Furno, and K. Leo, Organic Light-Emitting Diodes (OLEDs): Materials, Devices and Applicat ions, First. Woodhead Publishing, 2013.

P. Alto, P. P. Data, and D. Joshua, "United States Patent," vol. 2, no. 12, 2005.

R. H. Partridge, "Electroluminescence from polyvinylcarbazole films: 1. Carbazole cations," Polymer (Guildf)., vol. 24, no. 6, pp. 733–738, 1983.

C. W. Tang and S. A. Vanslyke, "Organic electroluminescent diodes," Appl. Phys. Lett., vol. 51, no. 12, pp. 9 13–915, 1987.

K. Leo, "Organic Semiconductor World, Record Charts." [Online]. Available: http://orgworld.de/. [Accessed: 01-Jan-2016].

M. Shukla, N. Brahme, R. S. Kher, and M. S. K. Khokhar, "Elementary approach to calculate quantum efficie ncy of polymer light emitting diodes," Indian J. Pure Appl. Phys., vol. 49, no. February, pp. 142–145, 2 011.

D. Hill, "The Optical Outcoupling of Organic Light Emitting Diodes," Thesis, no. June, 2008.

G. Gaertner and H. Greiner, "Light extraction from OLEDs with (high) index matched glass substrates," Org. Optoelectron. Photonics III, vol. 6999, no. 1, p. 69992T, 2008.

R. Meerheim, M. Furno, S. Hofmann, B. Lüssem, and K. Leo, "Quantification of energy loss mechanisms in organic light-emitting diodes," Appl. Phys. Lett., vol. 97, no. 25, pp. 1–4, 2010.

S. S. Olthof, "Photoelectron Spectroscopy on Doped Organic Semiconductors and Related Interfaces," p. 179 , 2010.

Y. He and R. Hattori, "Light output measurements of the organic light-emitting devices," Rev. Sci. Instrum., vol. 71, no. 5, pp. 2104–2107, 2000.

S. R. Forrest, D. D. C. Bradley, and M. E. Thompson, "Measuring the efficiency of organic light-emitting dev ices," Adv. Mater., vol. 15, no. 13, pp. 1043–1048, 2003.

C. Murawski, K. Leo, and M. C. Gather, "Efficiency roll-off in organic light-emitting diodes," Adv. Mater., v ol. 25, no. 47, pp. 6801–6827, 2013.