THE EFFECTS OF LIGHT SCATTERING ON OLED EFFICIENCY

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Introduction

OLED outcoupling efficiency is limited by several factors, one major factor is the limitation caused by internal reflection of light with the interface between organic layers including the anode and glass substrate. We approach this problem by adding a fairly exotic material to the OLED setup, which is strongly scattering light. We expect the scattering to lower total internal reflection and increase outcoupling efficiency. We compare the outcoupling 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.
- OLED efficiency on OLEDs brings high economic and ecological benefits.
- Tang and Van Slyke invented the first OLED in 1987 at Kodak labs.

THE PIN OLED STRUCTURE

Pin OLED 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 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 into the ETL, while the HBL is designed to stop holes from passing into the EML. If either case was to occur, there would be a disproportionate amount of recombination outside of the EML thereby lowering 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.

THERMAL EVAPORATION 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 cold.
- The thicknesses of the HBL and EBL is set at 10nm. The organic molecules are placed into crucibles at the bottom of the chamber, heated by Cu cold.
- The ETL, along with the scattering layer (120nm-Benzophenazinone) is varied as differing thicknesses: 40, 60, 80 and 100 nm for the ETL and 0, 20, 60 and 100nm for the 128-nm.
- Scattering efficiency is OLEDs brings high economic and ecological benefits.

Method

\[ \Phi_{\text{ext}} = \int \Phi_{\text{ext}}(\lambda) \, d\lambda = \sum \Phi_i(\lambda) \, d\lambda(2) \]

where \( \Phi_i \) is a function of \( \lambda \), the wavelength. \( \Phi_i \) is given by:

\[ \Phi_i = \frac{200}{\lambda} \int_{\lambda}^{\lambda_{\text{ref}}} \frac{L_{\text{out}}(\lambda)^2}{\lambda} \, d\lambda \]

where \( \lambda_{\text{ref}} \) is the area of the OLED. We can attain \( \eta_{\text{nuc}} \) by dividing the detected flux by the power and 

\[ \Phi_i = \frac{200}{\lambda} \]

\[ \Phi_{\text{ext}} = \frac{\lambda}{\lambda_{\text{ref}}} \]

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where \( \Phi_{\text{ext}} \) is the current through the OLED device and \( \lambda \) being the input voltage.

To measure \( \eta_{\text{nuc}} \), with our collected data we perform calculations by the given function:

\[ \eta_{\text{nuc}}(\%) = \frac{\int \Phi_{\text{ext}}(\lambda) \, d\lambda}{\int \Phi_{\text{ext}}(\lambda) \, d\lambda} \times 100 \]

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where \( \Phi_{\text{ext}}(\lambda) \) is a given wavelength on the electromagnetic spectrum, \( \lambda \) is Planck’s constant, \( c \) is the speed of light in a vacuum, and \( q \) is the elementary charge.

Results

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 EIE), 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 quantify the number 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, by developing new approaches to increase it.

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 IQE and luminous efficiency as a function of luminance. The same increase trend is seen for IQE and luminous efficiency as a function of current density. This agrees with the slight current decrease observed when the 20nm scattering layer is added for a total ETL thickness of 80nm.

EXTERNAL QUANTUM EFFICIENCY

The external quantum efficiency (EQE) is one of the most important figures of merit for OLEDs; it is defined as the ratio of photons emitted to the total number of photons generated in the OLED. Although almost all charge carriers injected 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 focuses on clarifying the reasons for the low outcoupling efficiency and on developing new approaches to increase it.

References


