Effects of Nano-Structure and Refractive Index on Light Extraction in OLEDs

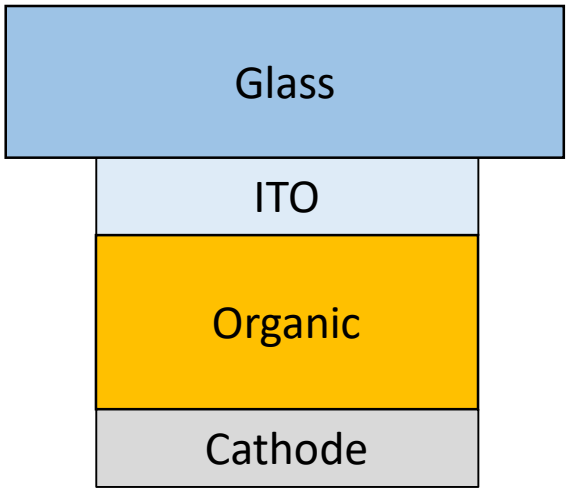
Franky So

Department of Materials Science and Engineering

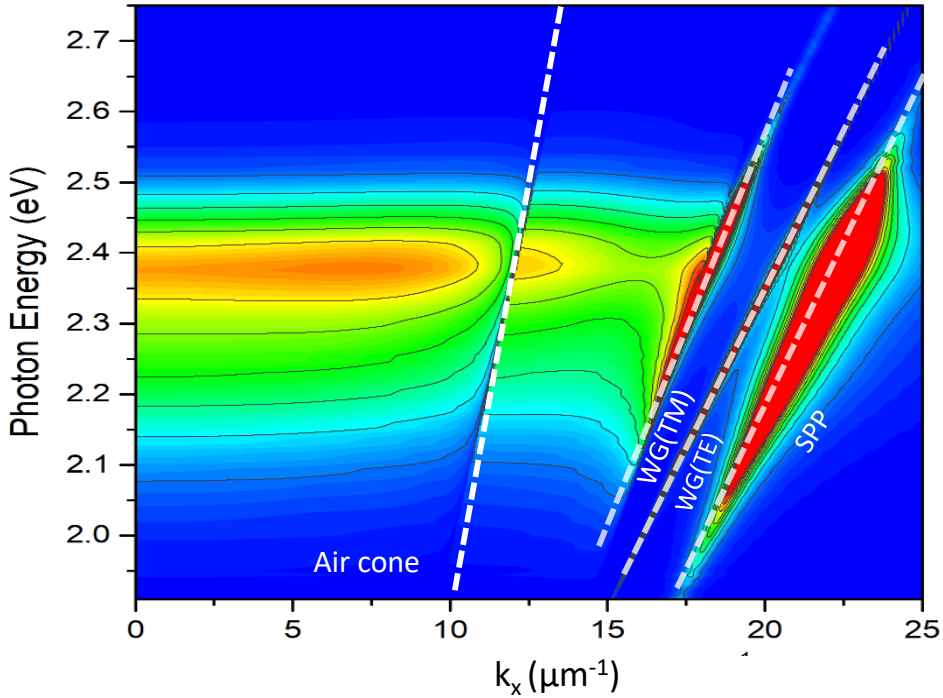
North Carolina State University

NC STATE UNIVERSITY

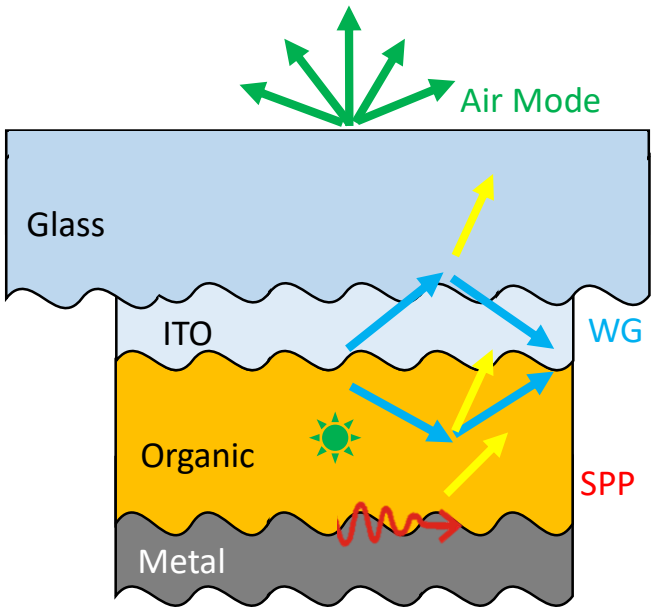
Optical Modes in an OLED



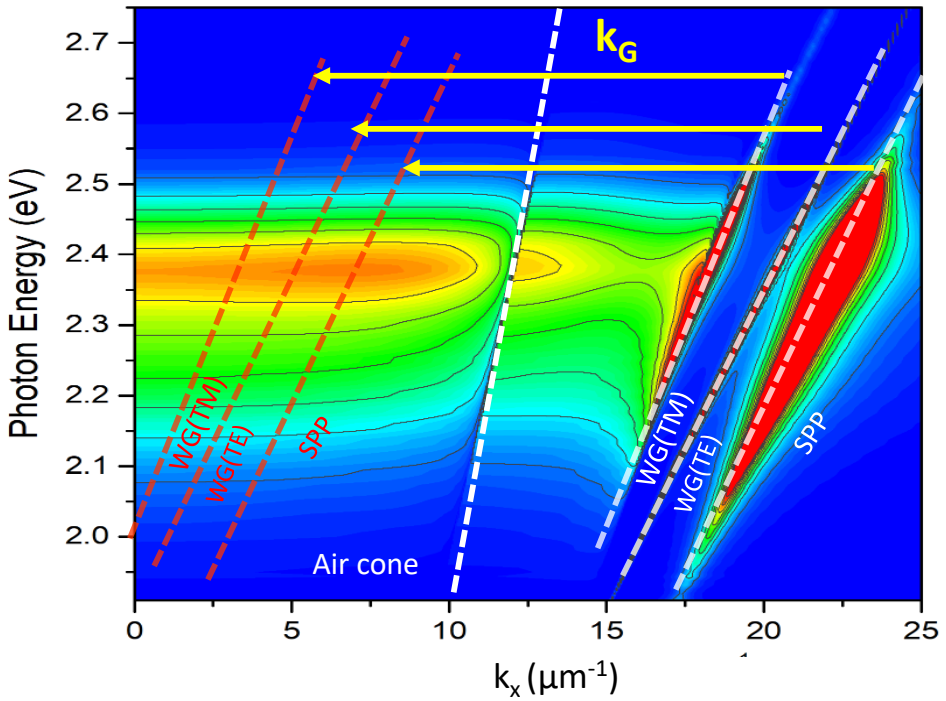
Simulated Mode Distribution



Light Extraction in Corrugated OLEDs



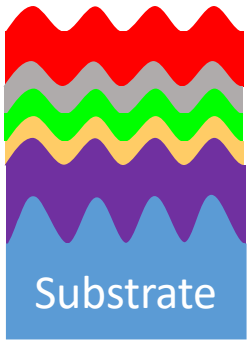
Simulated Mode Distribution

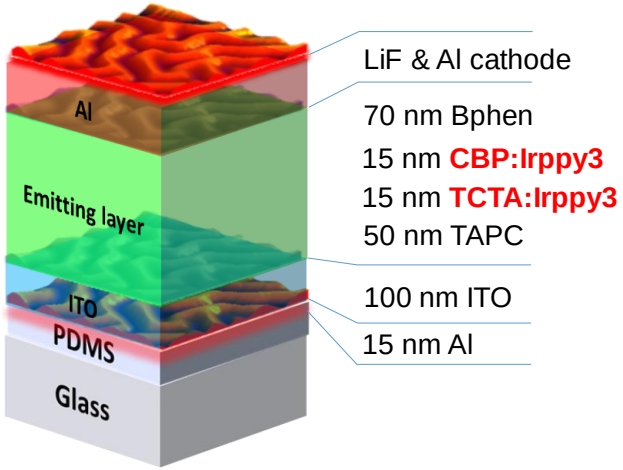


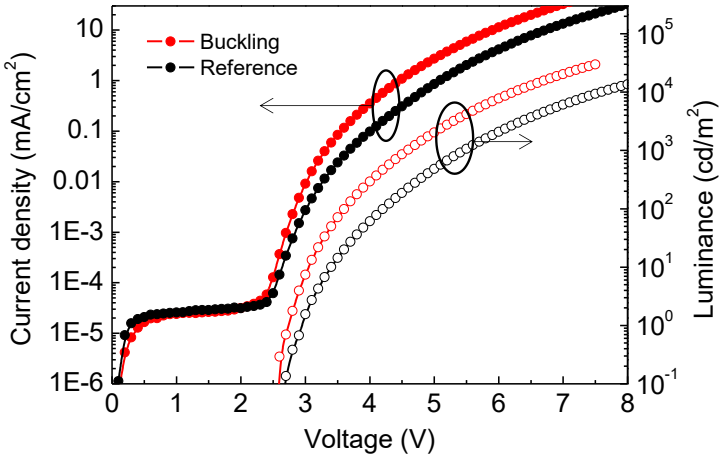
- Corrugated substrate works as diffraction grating
  - $k_G = 2\pi/\Lambda$
- Reduce k_x of trapped modes with corrugated structure
  - $k' = k - k_G$

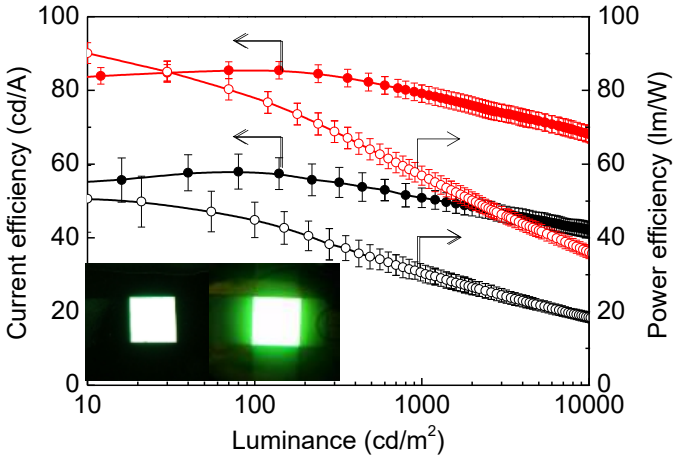
NC STATE UNIVERSITY

Corrugated OLEDs









◆ **Efficiency at 1000 cd/m²**

- Planar : 50.8 cd/A, 30.3 lm/W
- Buckling : 79.2 cd/A, 56.7 lm/W

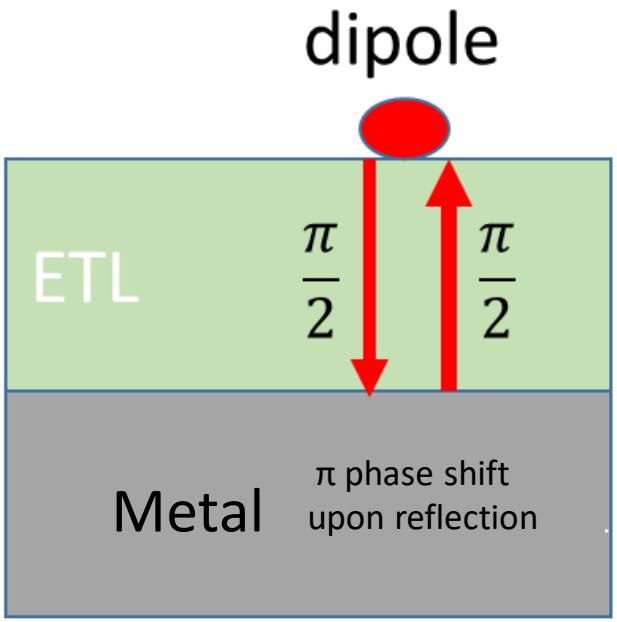
➡ **56% enhancement in cd/A and 87% enhancement in lm/W**

Adv. Opt. Mater. 1, 404 (2013)

NC STATE UNIVERSITY

Refractive index effects

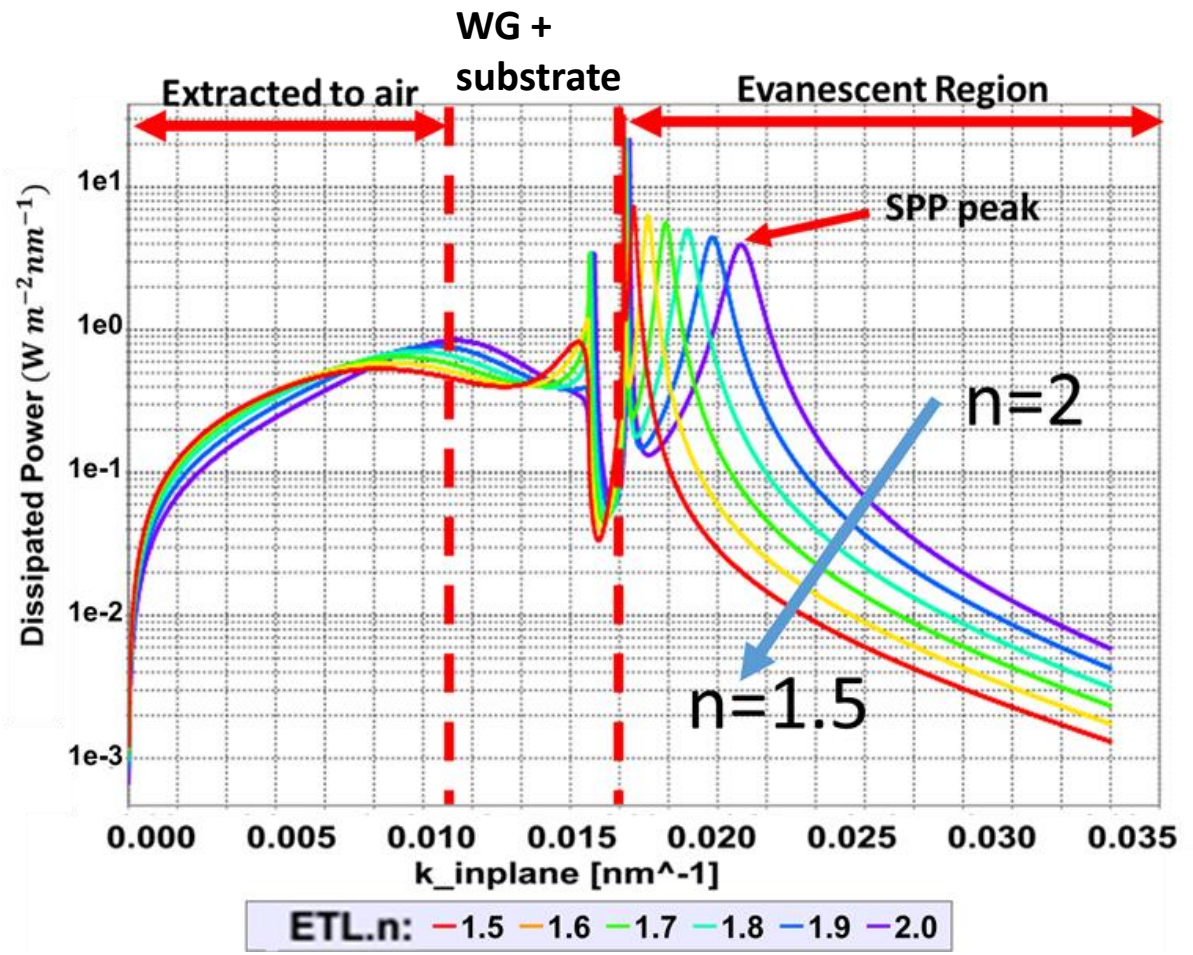
Effect of ETL refractive index



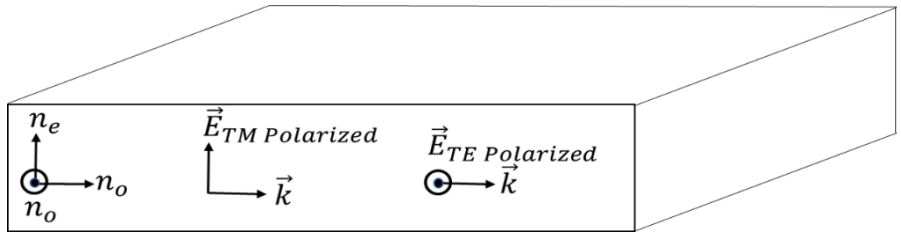
$$\frac{\lambda_o}{4n_{ETL}}$$

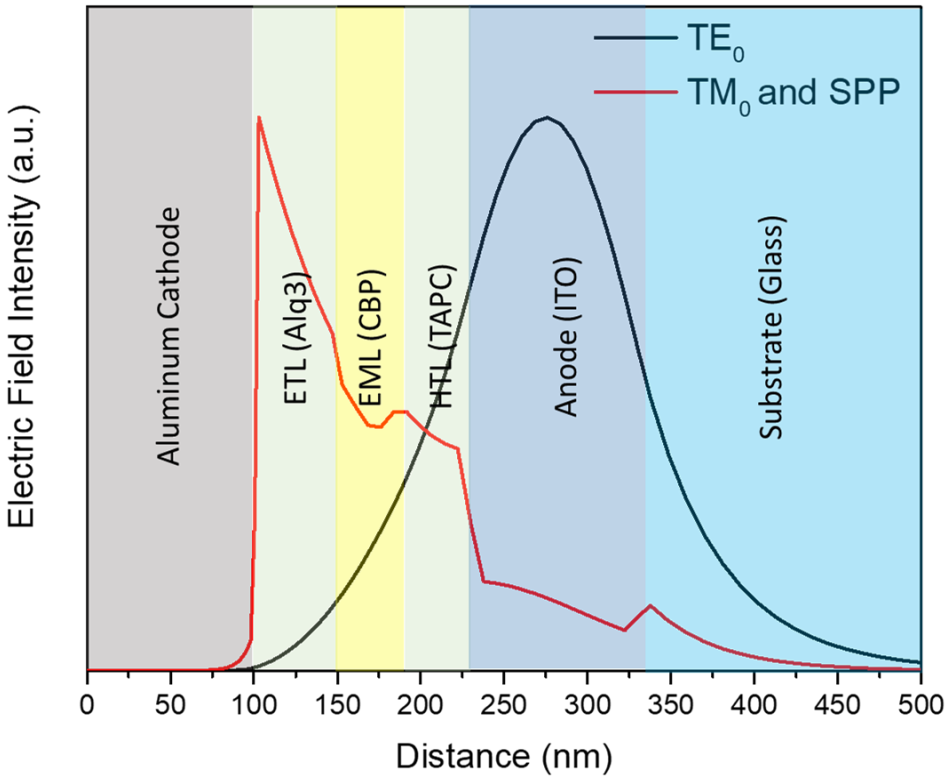
$$k_{in\_SPP} = \frac{2\pi}{\lambda}\left(\frac{\varepsilon_{cathode} \cdot \varepsilon_{ETL}}{\varepsilon_{cathode} + \varepsilon_{ETL}}\right)^{\frac{1}{2}}$$

Effect of ETL refractive index



Optical mode distribution



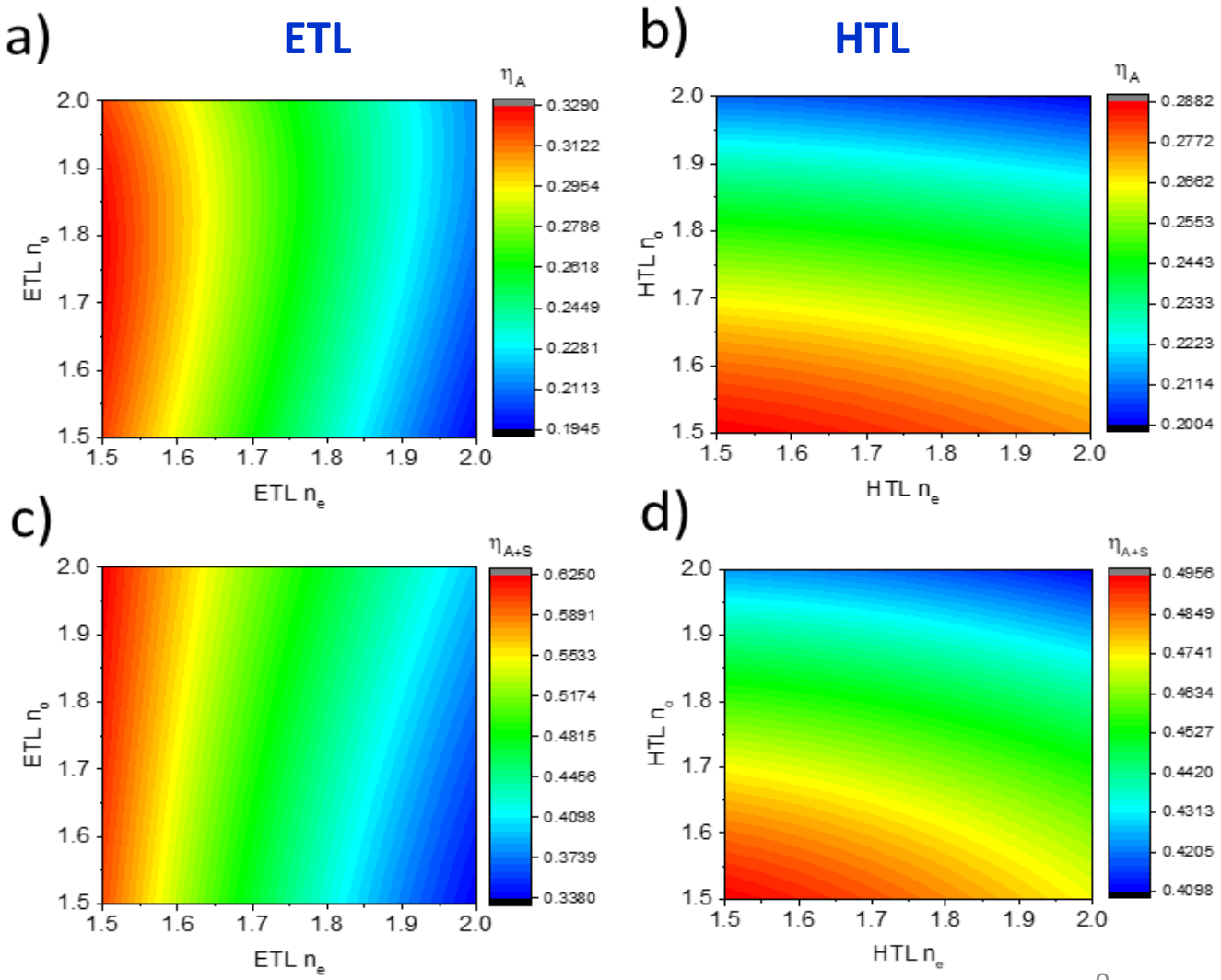


NC STATE UNIVERSITY

Effect of ETL and HTL refractive indices

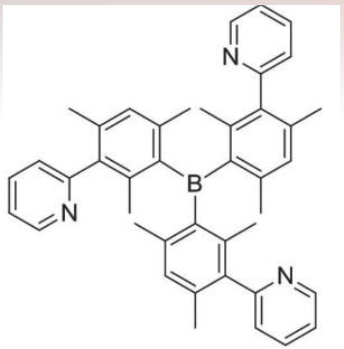
Air

Air + substrate

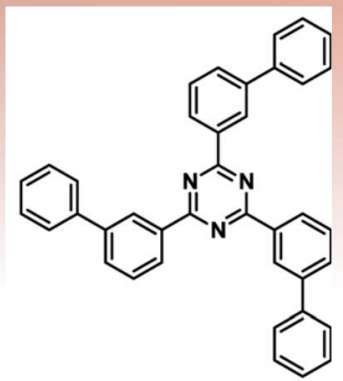


NC STATE UNIVERSITY

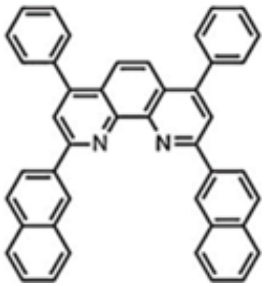
Effect of refractive index of ETLs



3TPYMB

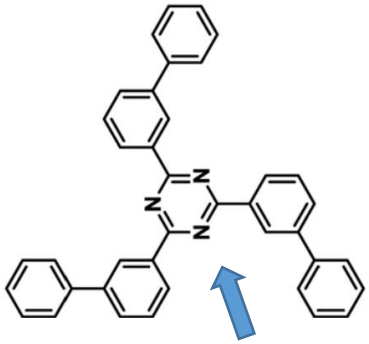


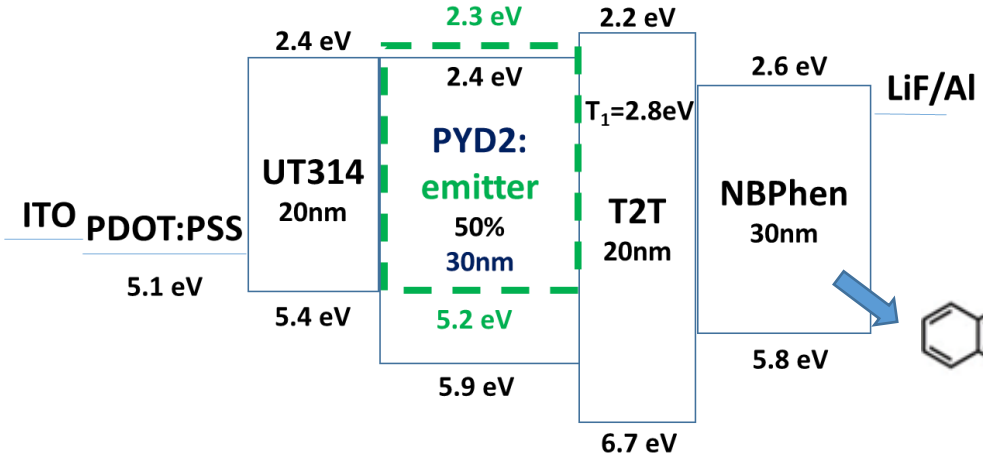
T2T

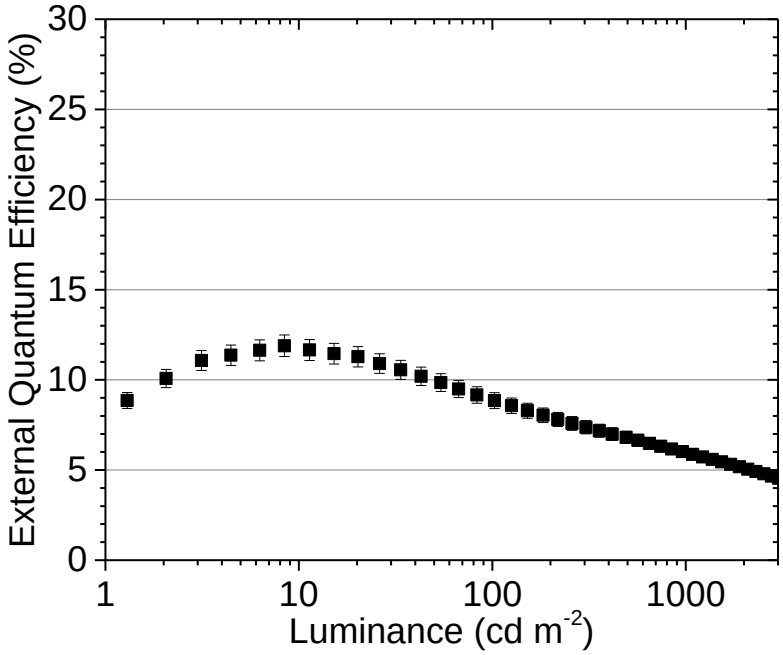


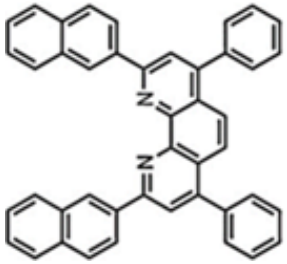
NBPhen

OLED using T2T/NBPhen as ETL





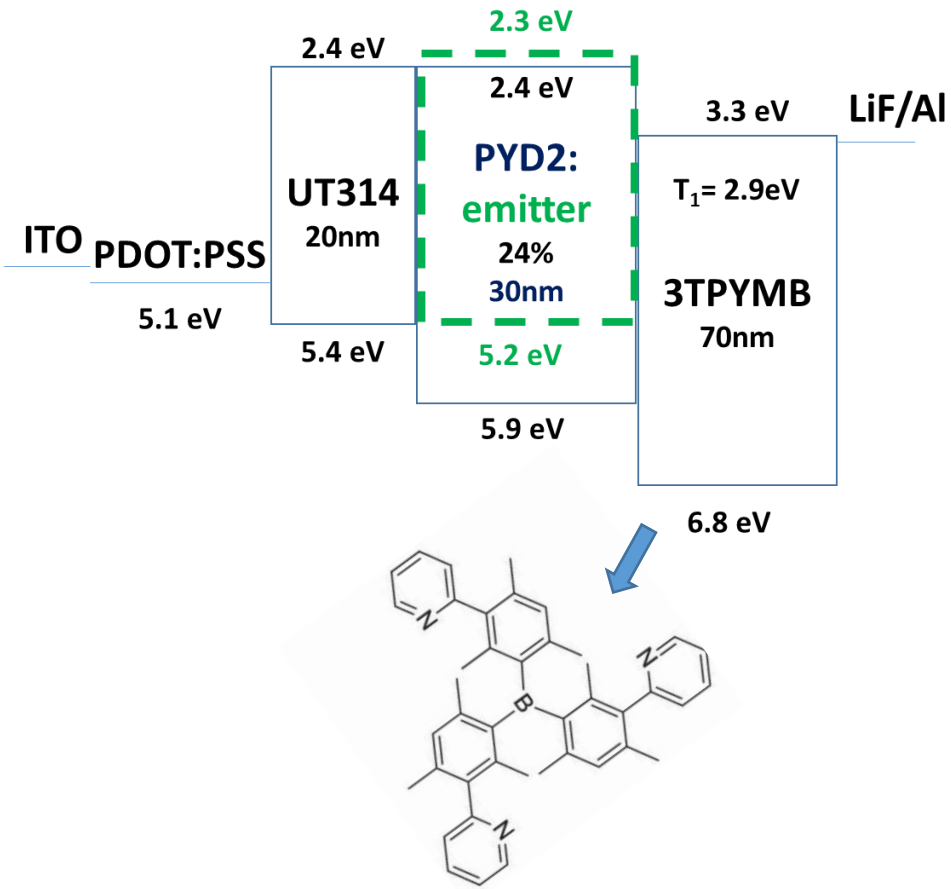


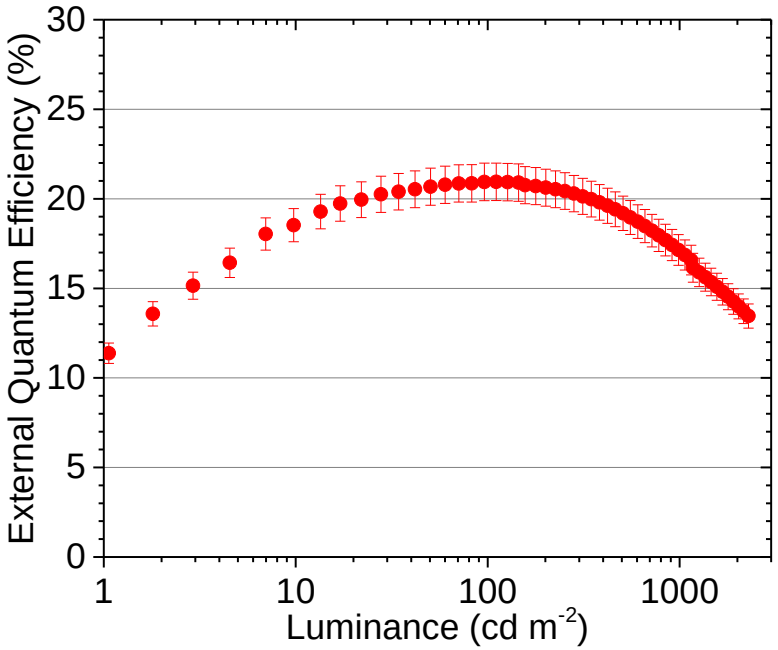


- Maximum EQE of 12% achieved. Close to the 14% expected EQE based on 70% PLQY and 20% light outcoupling.

NC STATE UNIVERSITY

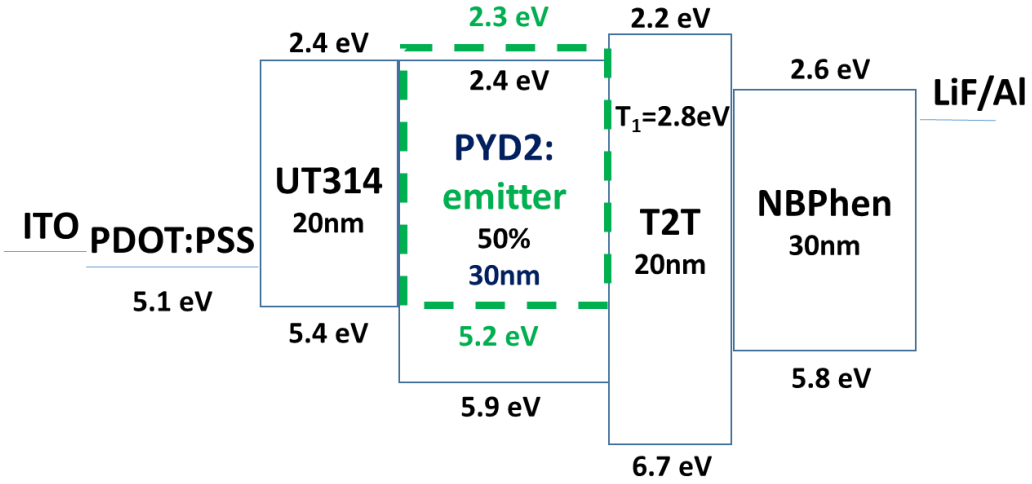
Device using 3TPYMB

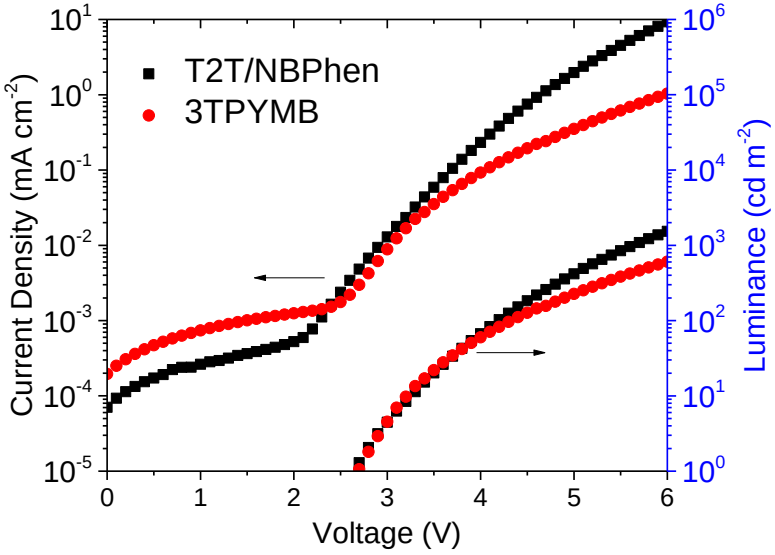


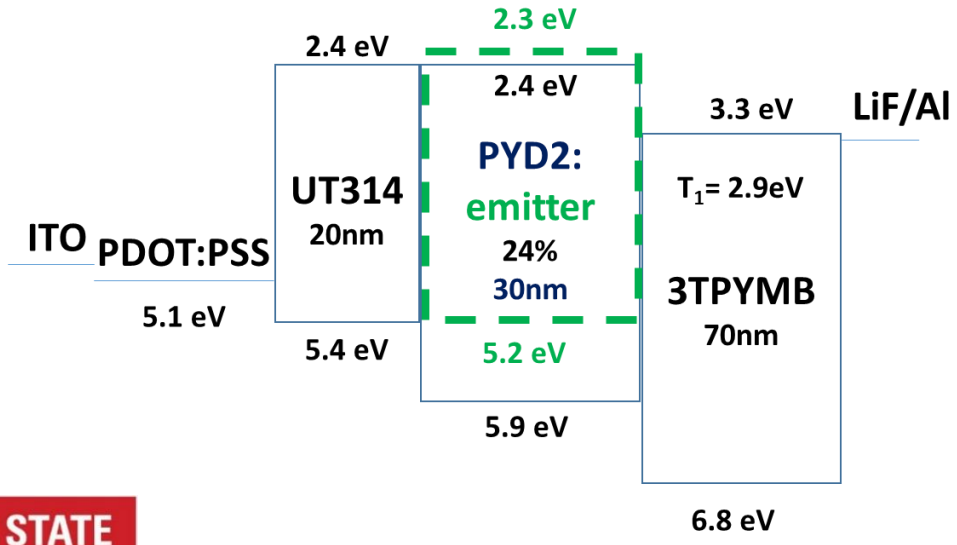


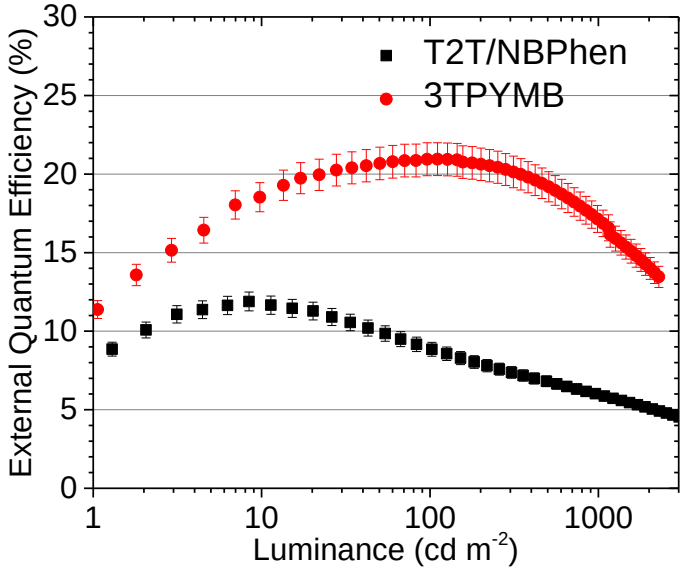
- A maximum EQE of 21% was achieved using 3TPYMB. Nearly 75% higher than the T2T/NBPhen device.

Comparing two devices





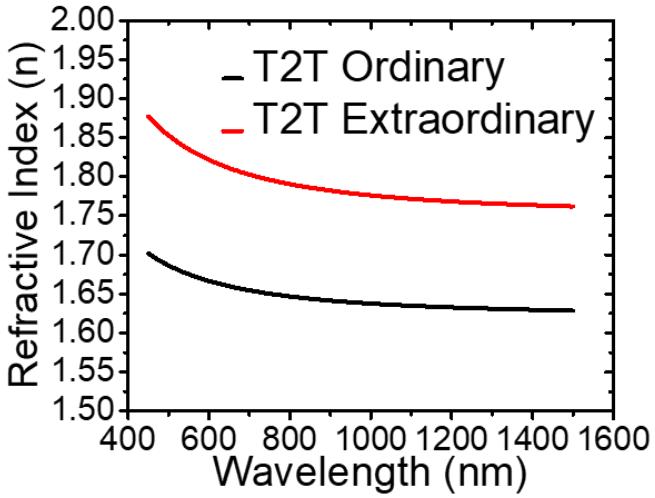


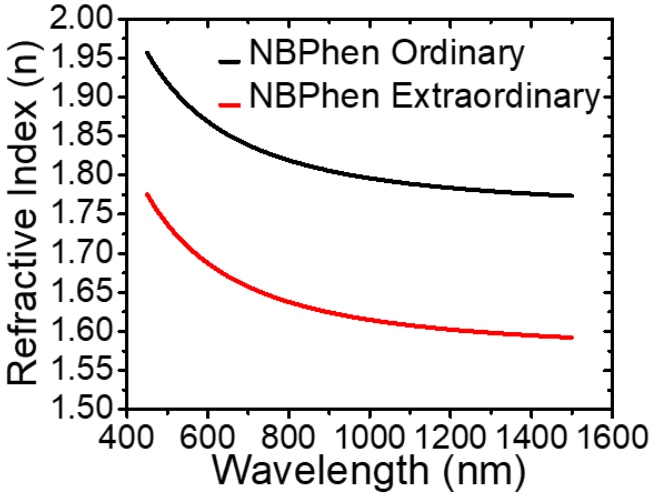


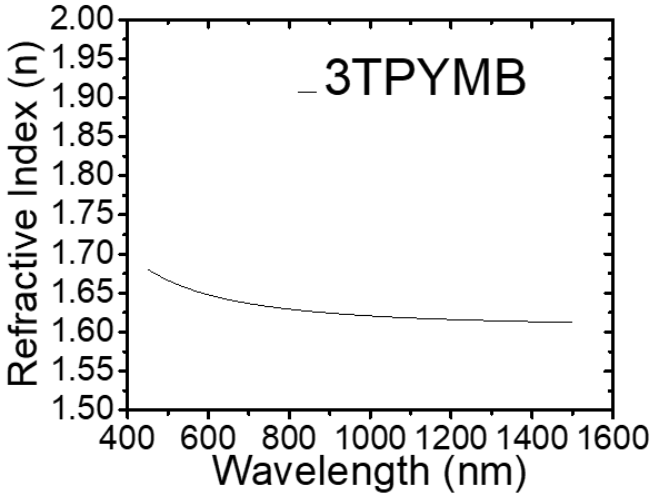
NC STATE UNIVERSITY

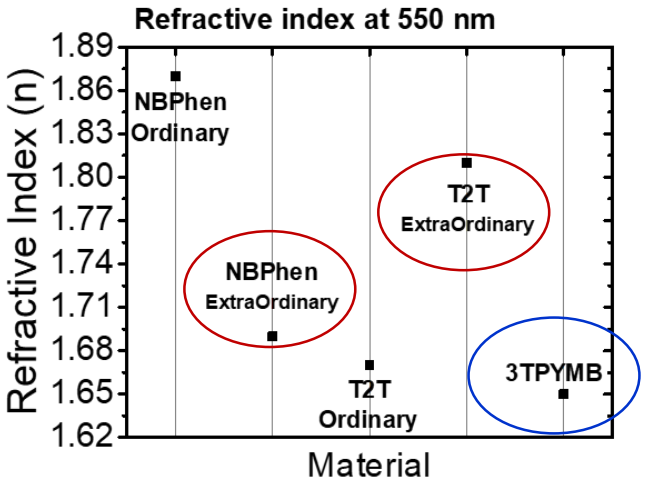
Refractive indices of ETLs

Amin Salehi





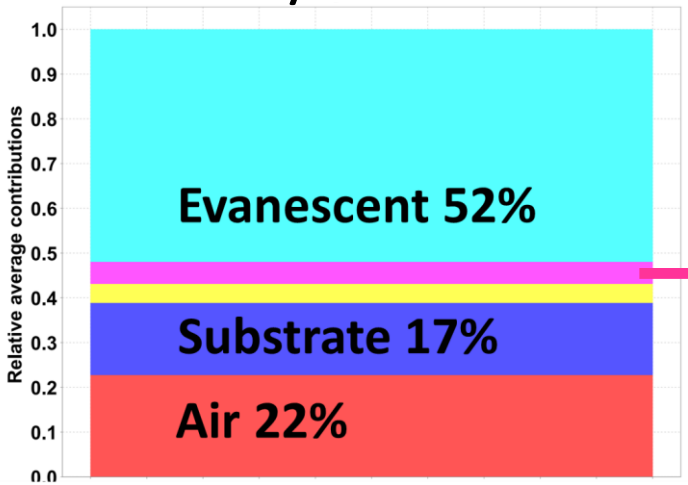




- 3TPYMB has the lowest refractive index.

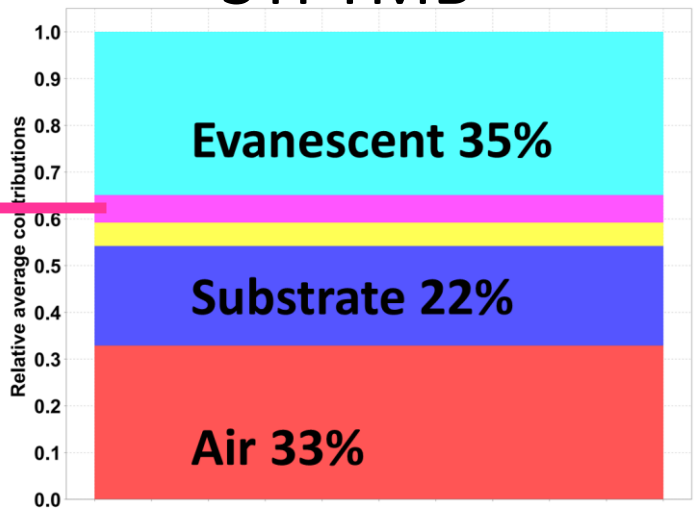
Index Effect on Optical Mode Profile

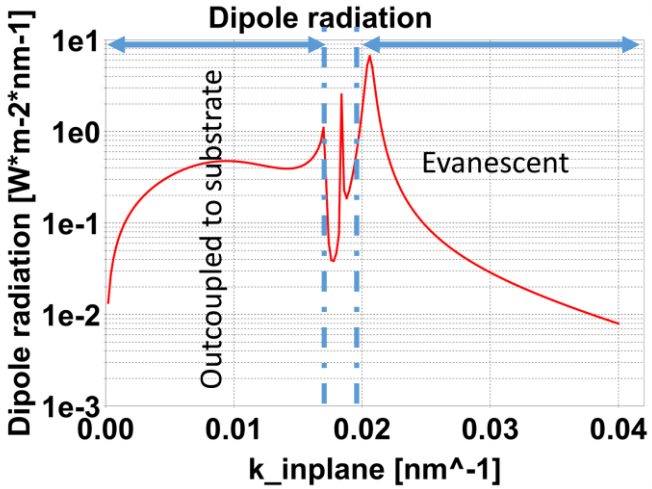
T2T/NBPhen

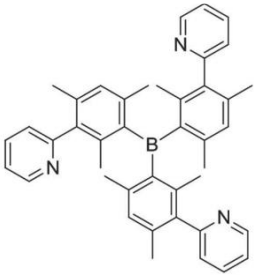


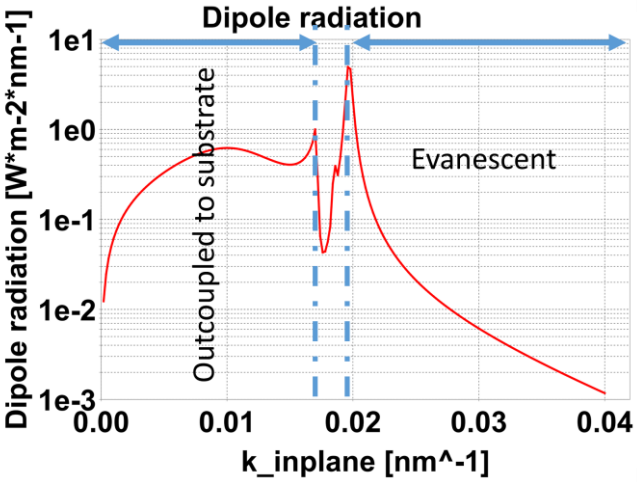
Waveguide ~ 5%

3TPYMB





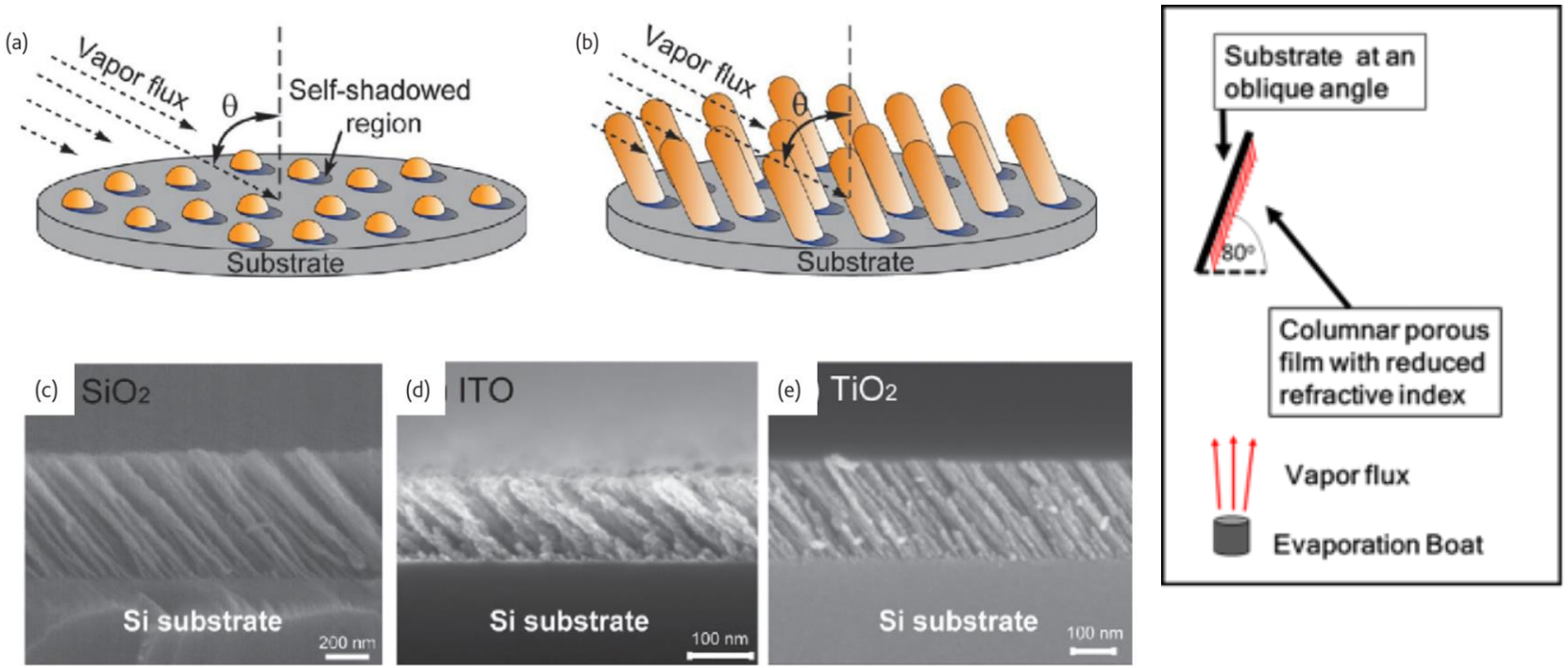




A. Salehi, Adv Opt Mater 5, 1700197 (2017)

Index Manipulation by Oblique Angle Deposition

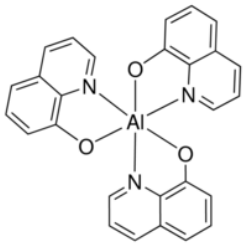
Lowering the index by OAD



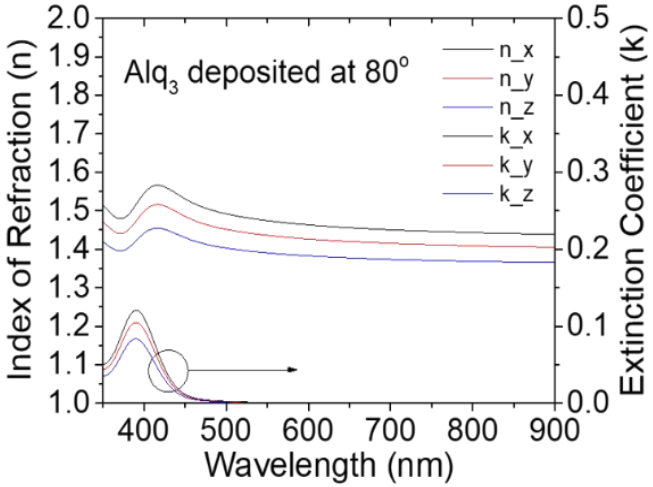
Plawsky et al. *Materials Today* (2009)

Barranco, Angel, et al. *Progress in Materials Science* (2016)

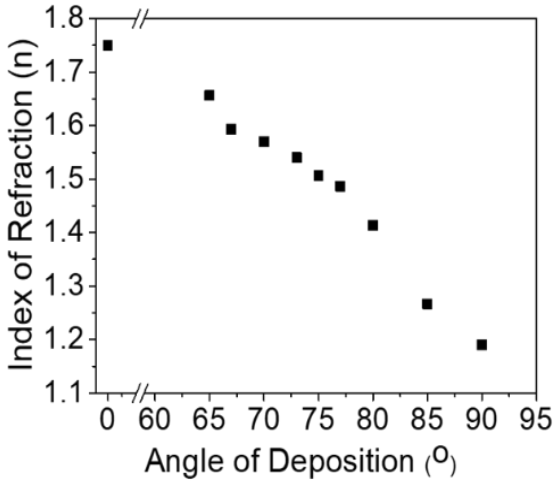
Oblique Angle Deposition of Alq3



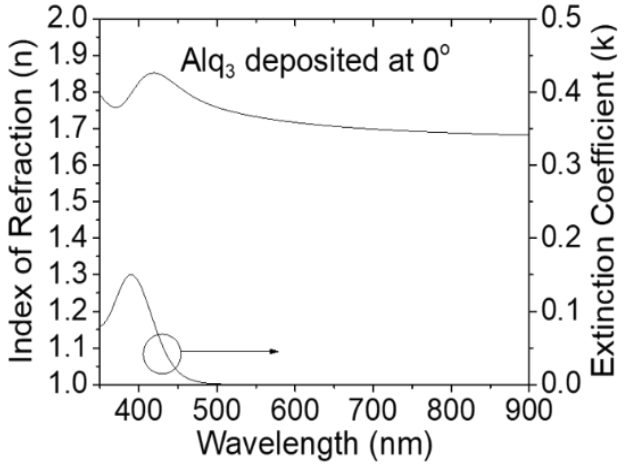
A)



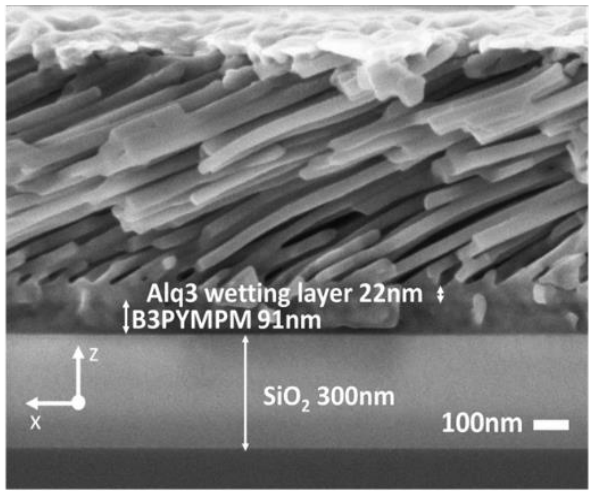
C)



B)

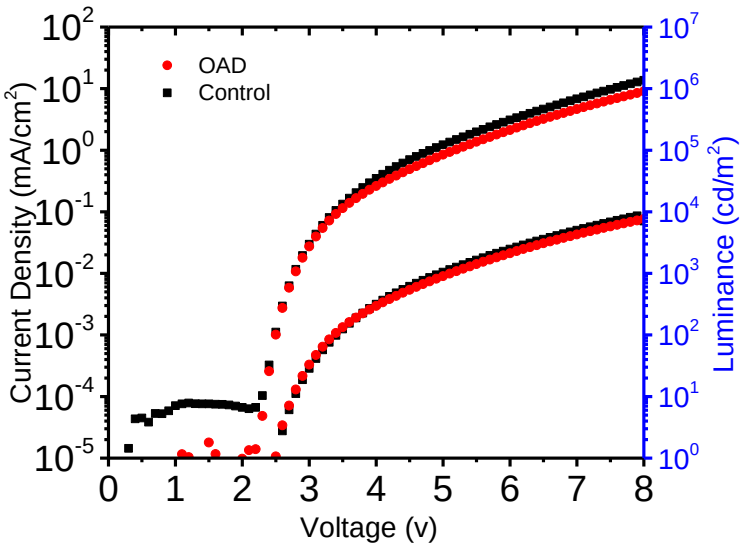


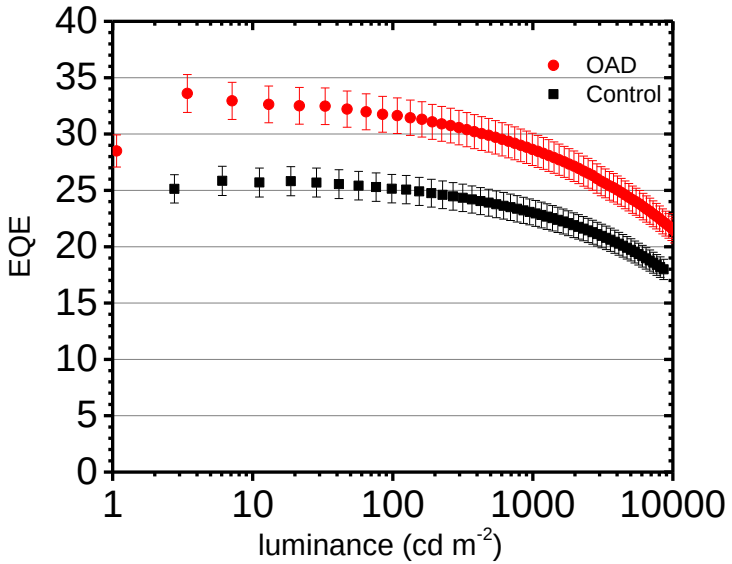
D)

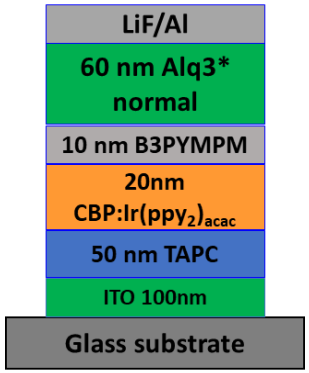


NC STATE UNIVERSITY

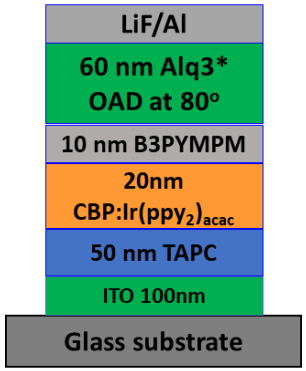
OLED devices using the OAD Alq3 ETL







Control



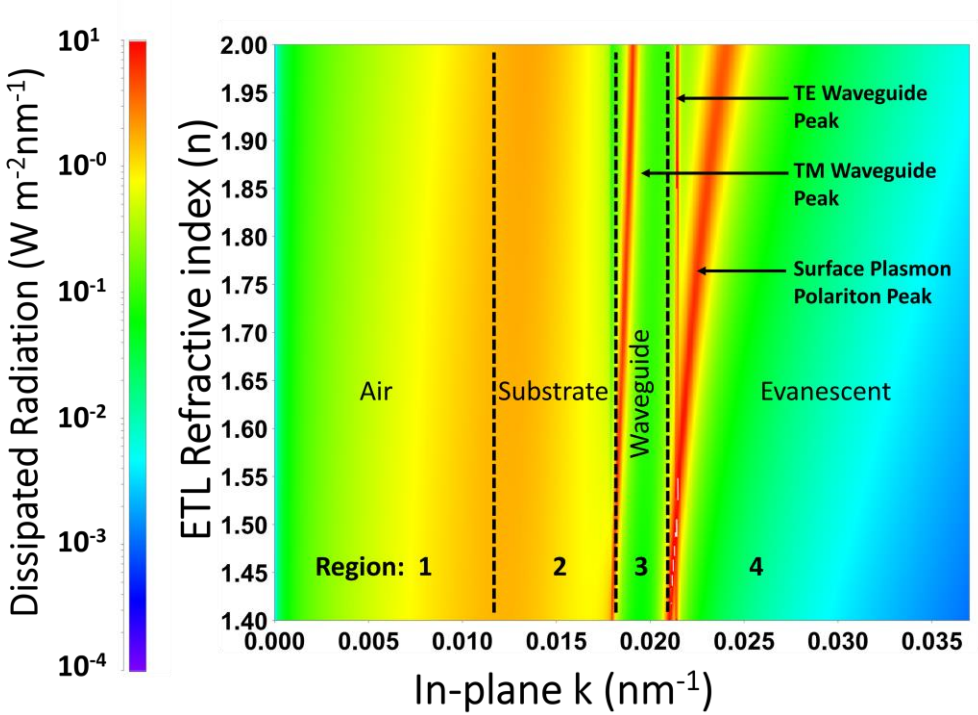
OAD

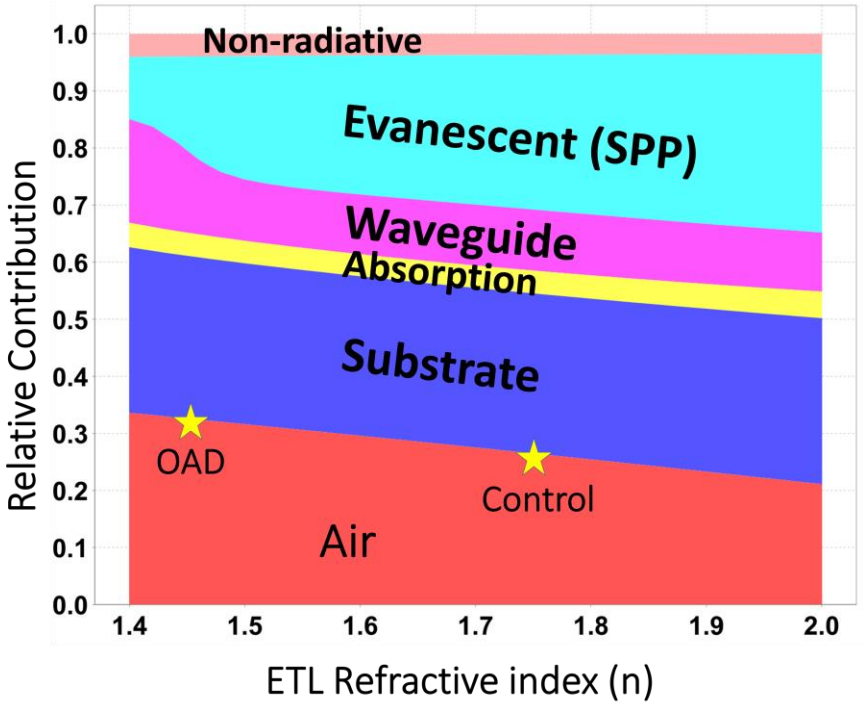
*The last 50 nm of Alq3 was doped with Cs_2CO_3

A. Salehi, ACS Appl Mater Interfaces 10, 9595 (2018)

NC STATE UNIVERSITY

Power Dissipation and Mode Analysis





Summary

- Reducing refractive index of the OLED layers can significantly increase light extraction.
- The refractive index of ETL has the largest impact on light extraction.
- OLED device using OAD Alq3, showed nearly a 30% enhancement in external quantum efficiency.