Light Extraction Technologies in Organic Light Emitting Devices for Lighting Applications

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Cambrios Technologies

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Light Extraction Technologies

Outline

- Energy Losses in OLED
- External Outcoupling Technologies
- Internal Outcoupling Technologies
- Cathode Outcoupling Technologies

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Energy Losses in OLED

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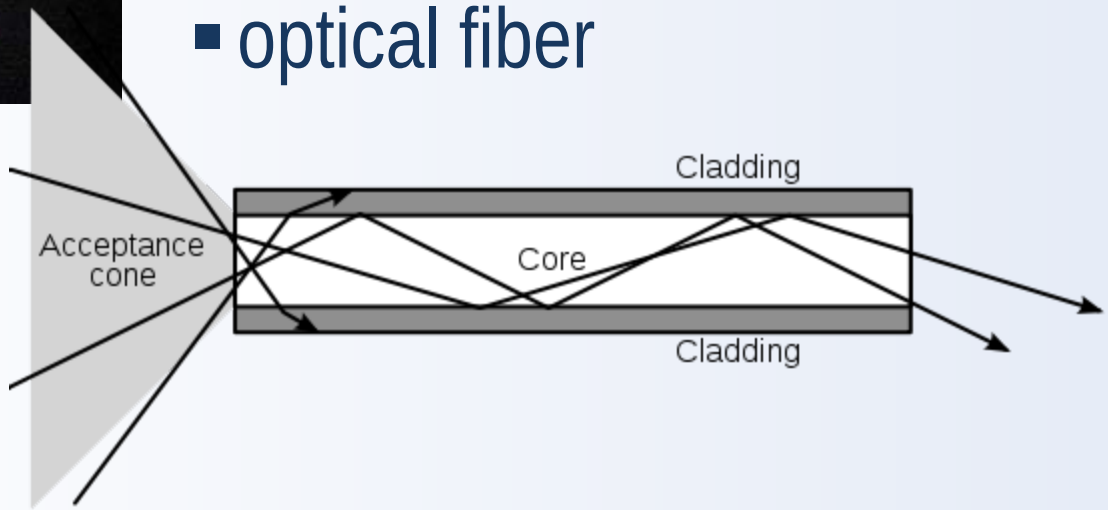
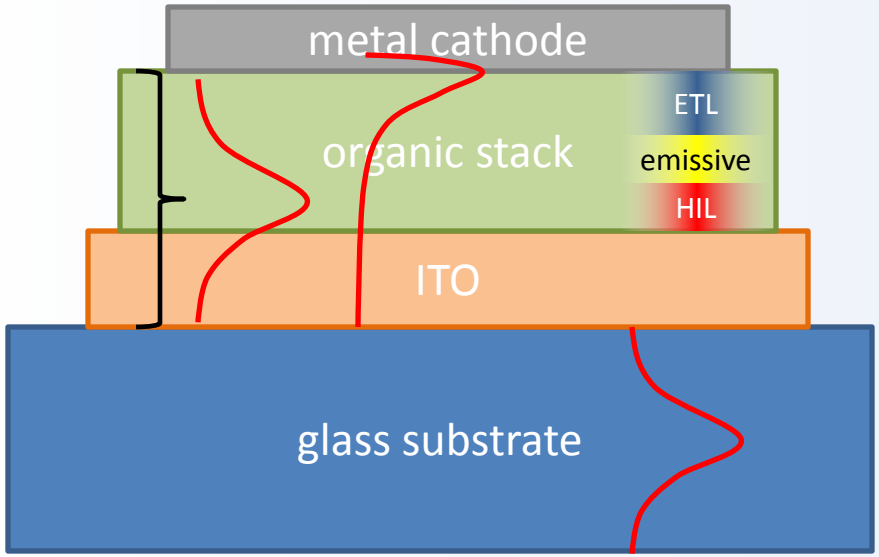
Energy Losses in OLED

Optical Waveguides

- light is being transported in a medium with high index of refraction due to total reflection at the interface
- optical fiber



Energy Losses in OLED



index of refraction
n = 1.7 … 1.85

n = 1.8 … 2.0

n = 1.5

"bottom emitting structure"

- wave guiding is also present in OLED
  - wave-guided mode in **organic/ITO**
  - wave-guided mode in **glass substrate**
- losses on cathode
  - near-field interaction between the dipole and cathode (strong function of exciton-cathode distance)
  - charge density oscillations (surface plasmon polaritons, SPP)

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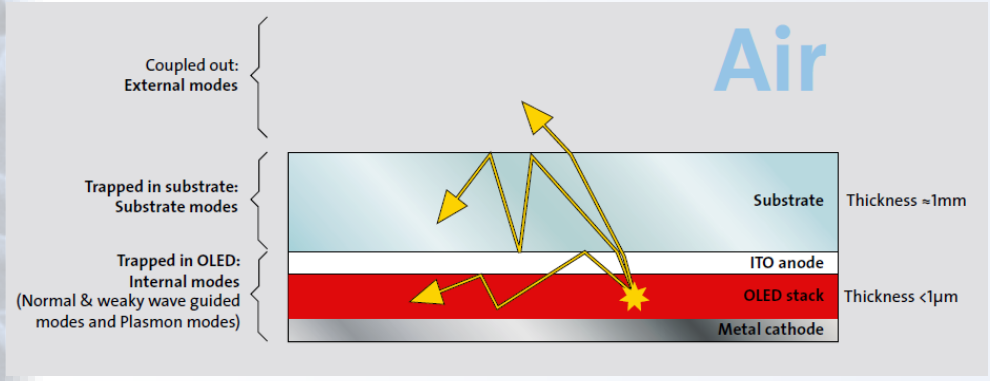
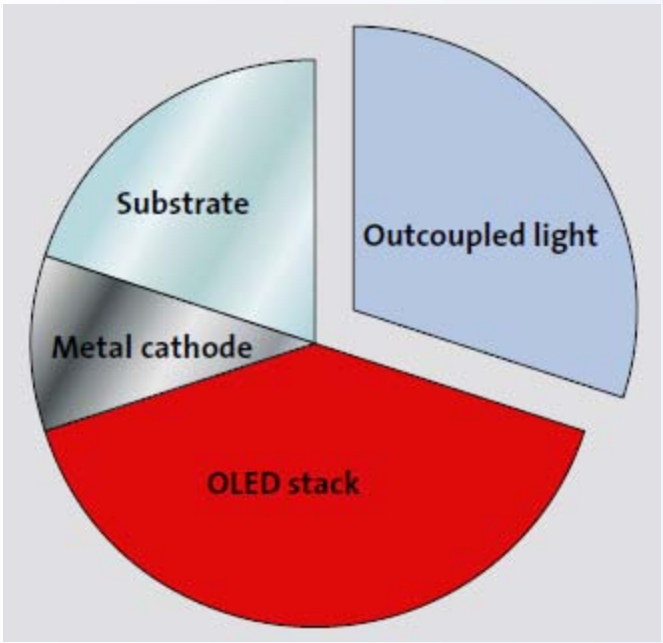
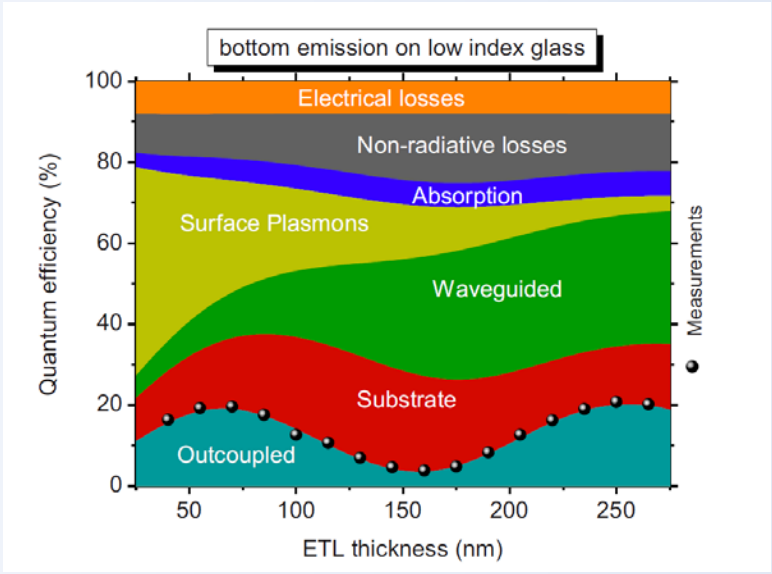
Energy Losses in OLED



source: Novaled AG





source: Meerheim et al., Appl Phys Lett 97, p253305 (2010)

- only 20 … 30% of light is actually coupled out
- work on extraction from
  - substrate → external
  - OLED stack → internal

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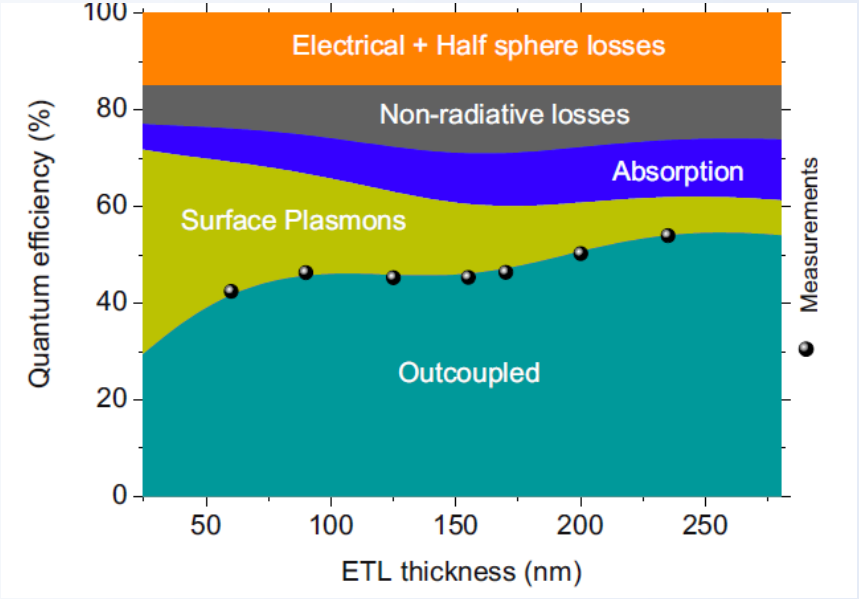
External Outcoupling Technologies

External Outcoupling Technologies

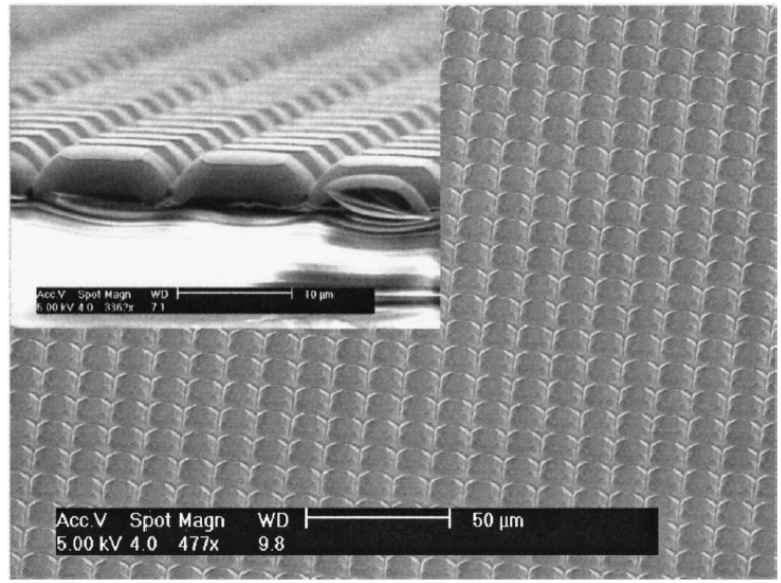
- use of high-index substrate → high cost
- no impact on organic/ITO mode
- increase in outcoupling by 2x

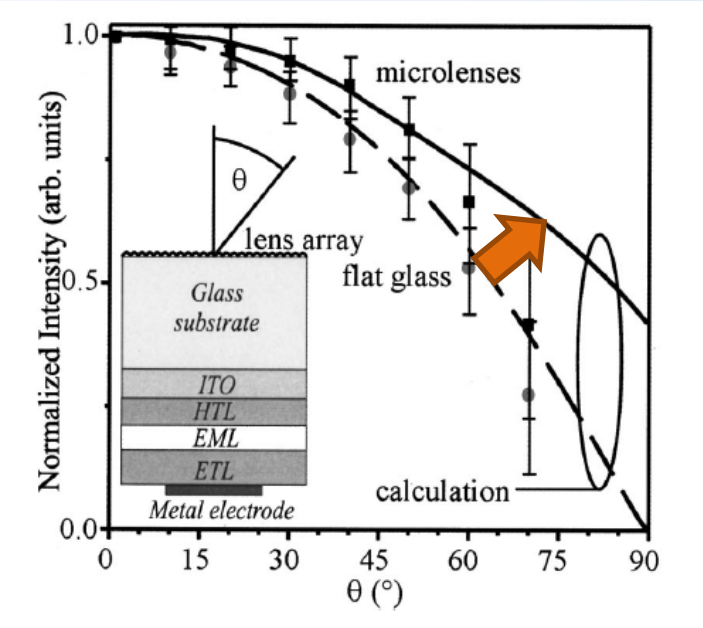


source: Meerheim et al., Appl Phys Lett 97, p253305 (2010)

External Outcoupling Technologies

- outer surface of substrate modified to decrease substrate mode
- microlens array: 50% increase in outcoupled light



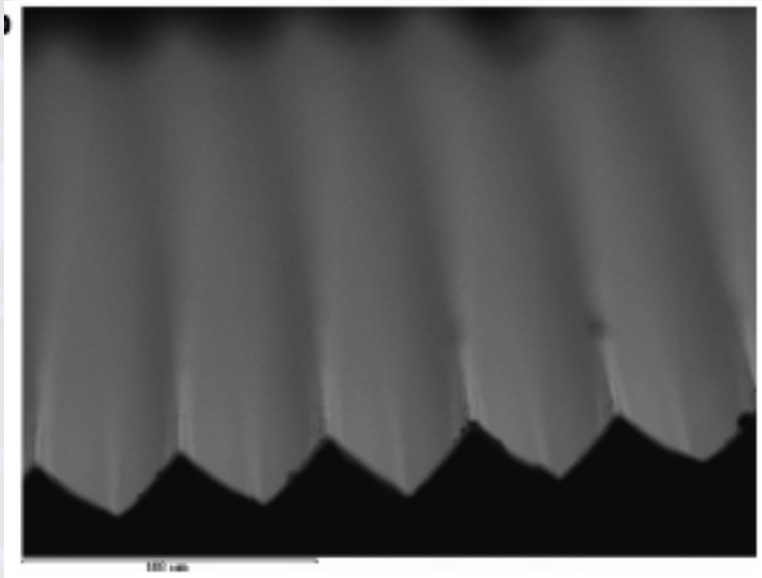


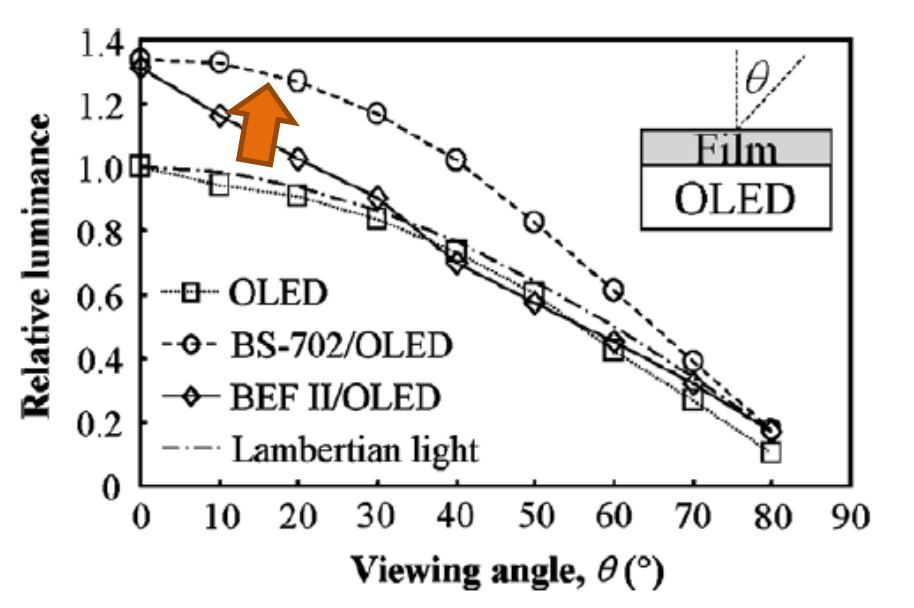
source: Möller et al., J Appl Phys 91, p3324 (2002)

External Outcoupling Technologies

- brightness enhancement films (eg. 3M BEF 90/50)

source: Lin et al., Opt Comm 275, p464, (2007)



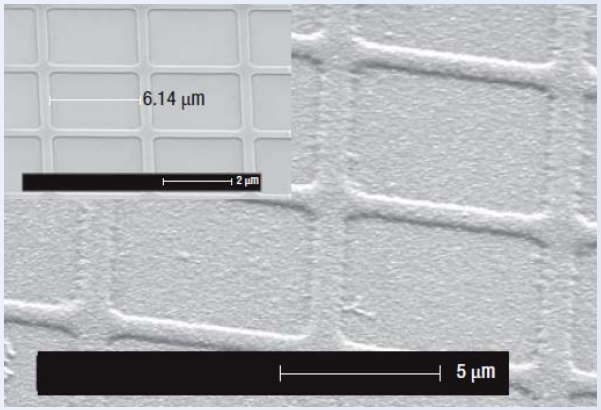


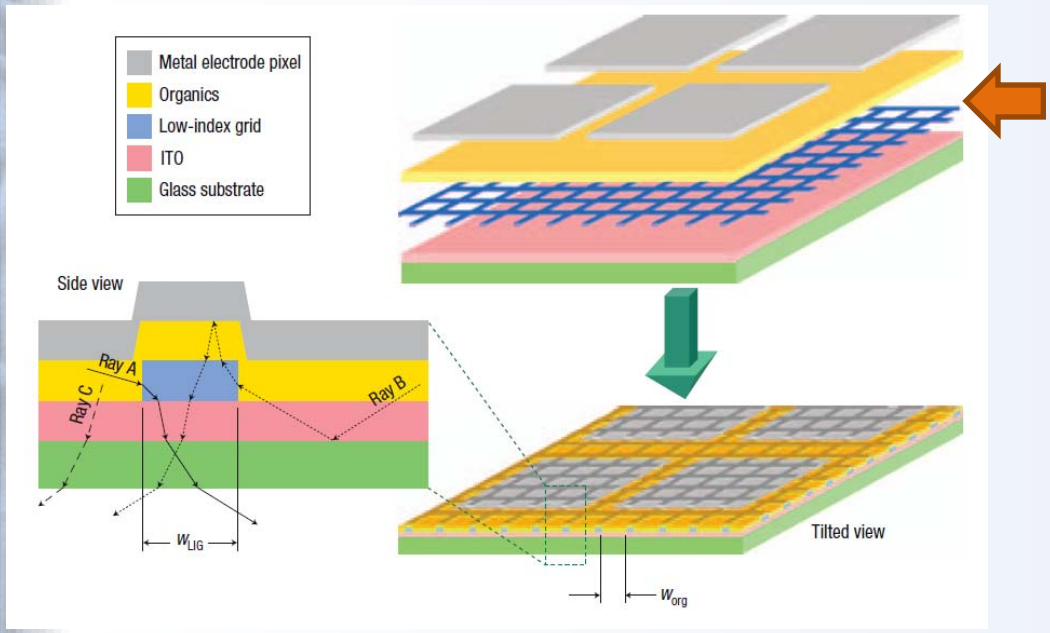
Internal Outcoupling Technologies

incorporating patterned grids

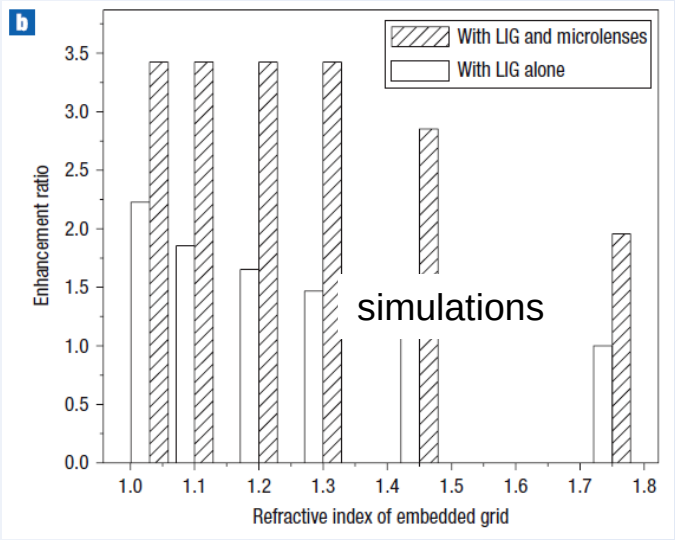
Internal Outcoupling Technologies

- low-index-grid on top of ITO layer
  - grid material: SiO_2 (n=1.5)
  - grid patterned by photolith
  - power efficiency was improved by 2.3x



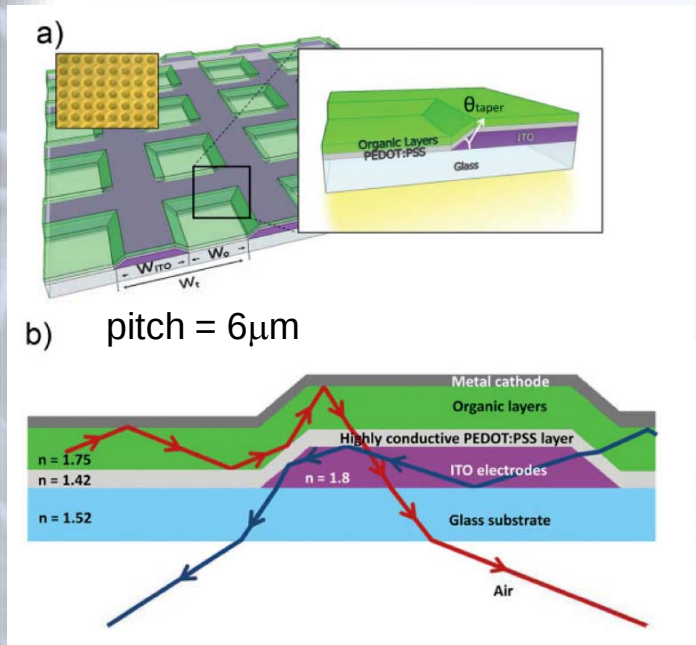


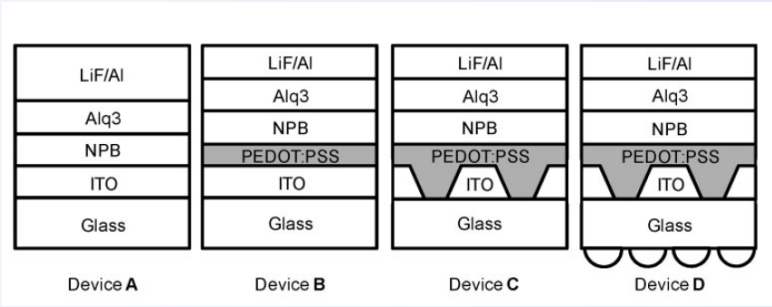
source: Sun et al., Nature Photonics, Vol 2, p483 (2008)

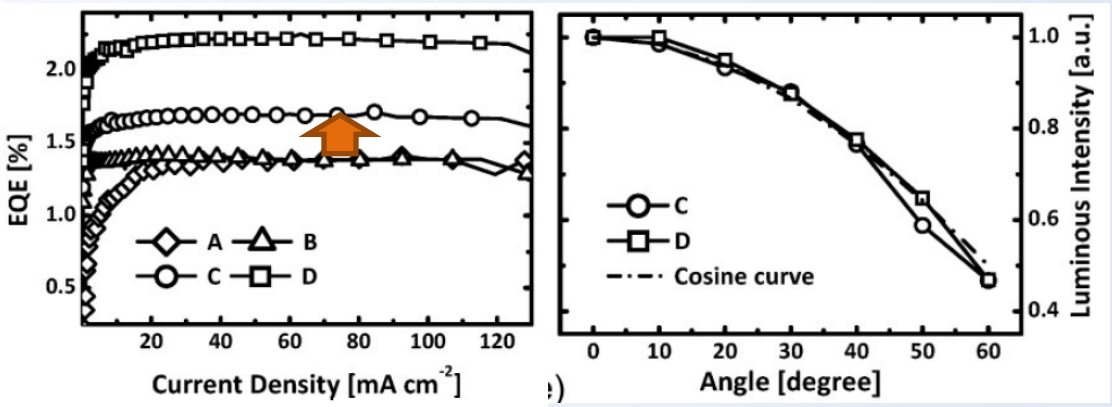


Internal Outcoupling Technologies

- patterned ITO, use of conductive polymer
  - grid patterned by photolith, neg impact on sheet resistance
  - power efficiency was improved by 74%





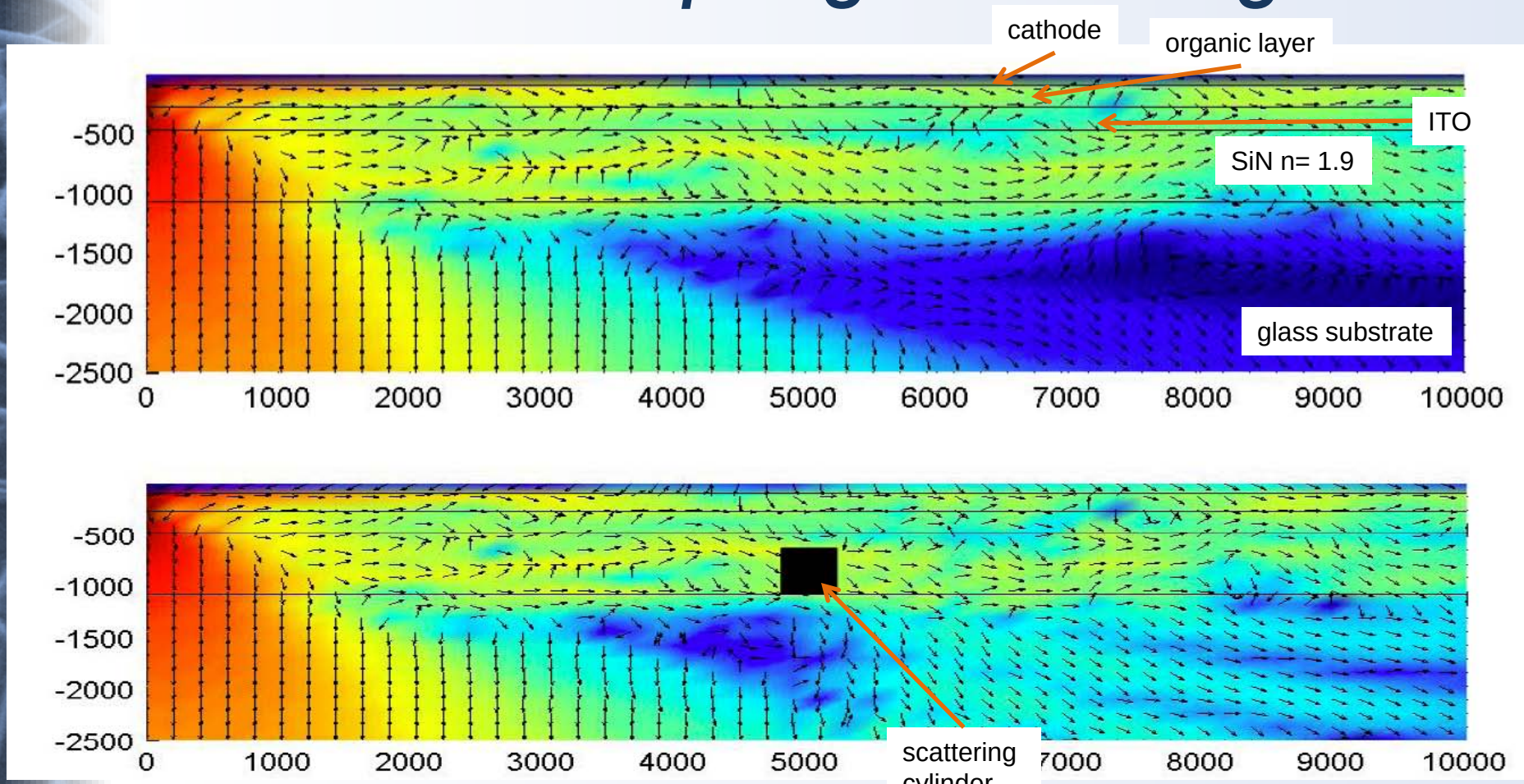


source: Koh et al., Adv Mater, p1849 (2010)

Internal Outcoupling Technologies

incorporating randomly distributed scattering centers

Internal Outcoupling Technologies



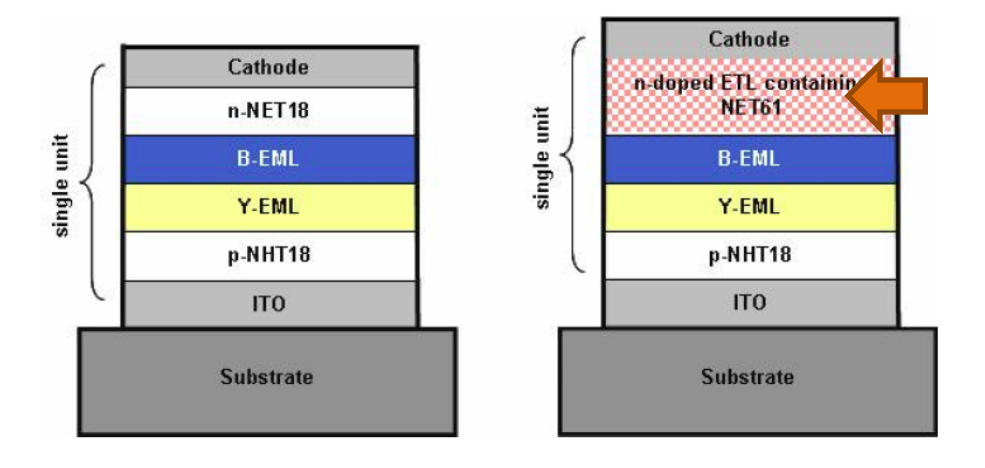
source: Greiner at al., Proc SPIE 5214, p248 (2004)

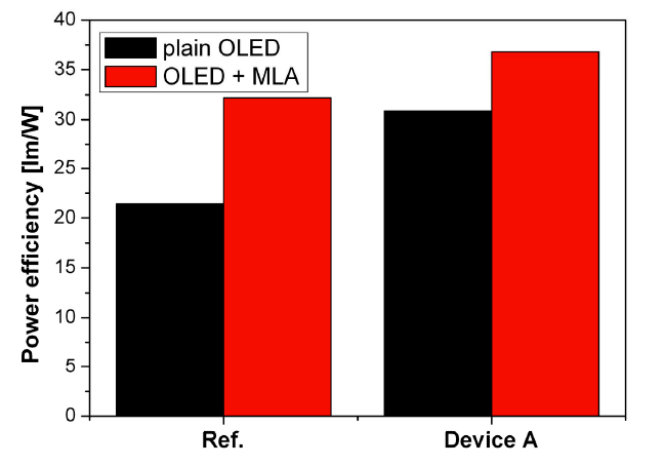
- simulated light propagation with scattering center
  - Poynting vector shows energy direction, color shows intensity

Internal Outcoupling Technologies

- ETL material induced scattering from cathode
  - evaporated material underneath the cathode
  - power efficiency was improved by 71%

source: Canzler (Novaled) et al., SID Digest, p975 (2011)

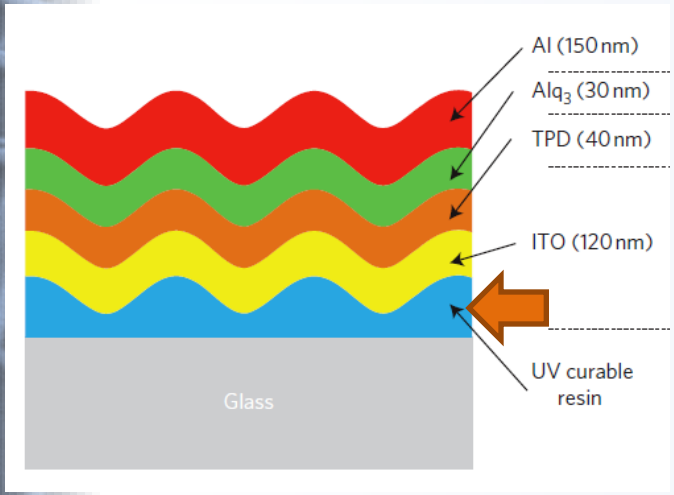




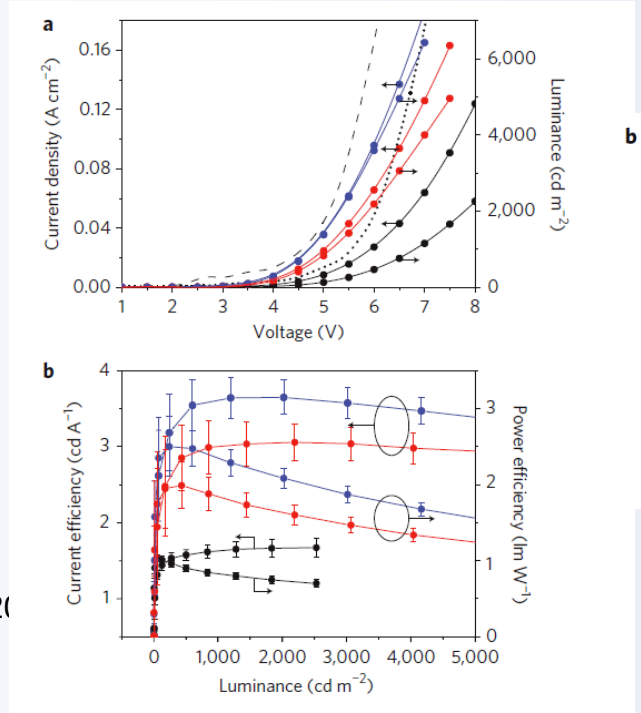
Remark: SPP reduction due to cathode morphology?

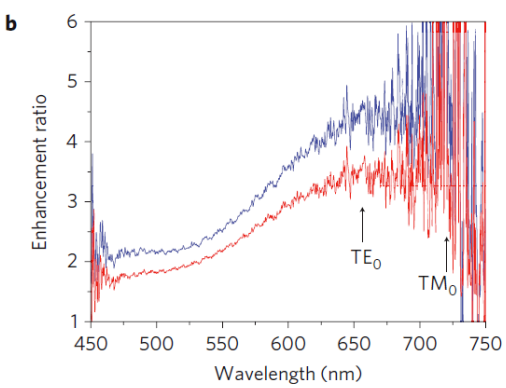
Internal Outcoupling Technologies

- "buckles" underneath ITO and organic stack
  - PDMS stamp with "buckles" used to transfer features to UV-curable resin before ITO was sputtered onto this layer
  - power efficiency was improved by 80% … 400%



source: Koo et al., Nature Photonics 4, p222 (2(





Remark: SPP reduction due to cathode morphology?

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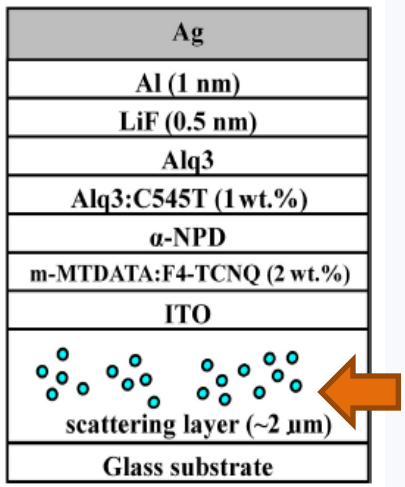
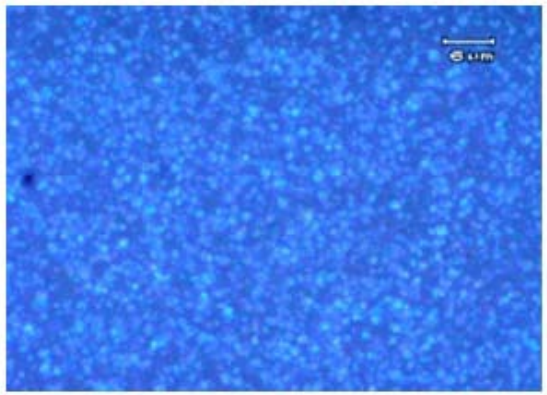
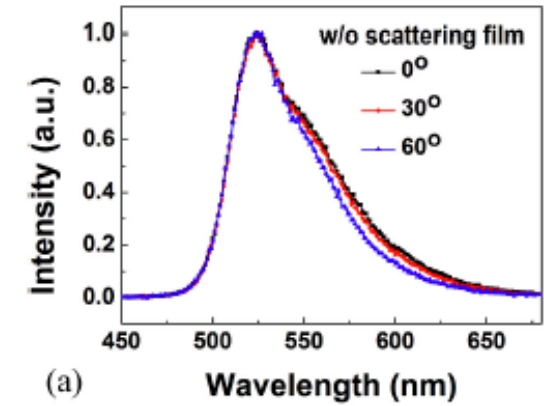
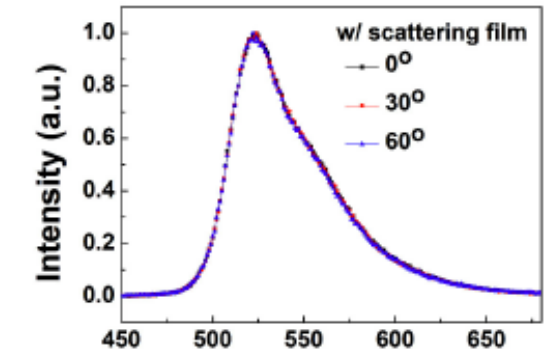
Internal Outcoupling Technologies

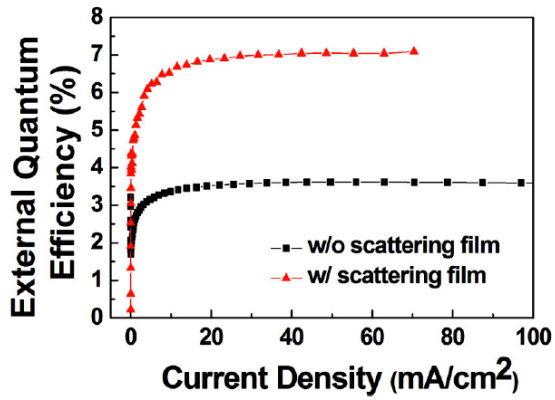
- scattering layer between ITO and glass substrate
  - TiO_2 particles (size 400nm)
  - more than 100% improvement in efficiency
  - better color stability vs. angle











source: Chang et al., Journal SID 19/2, p196, (2011)

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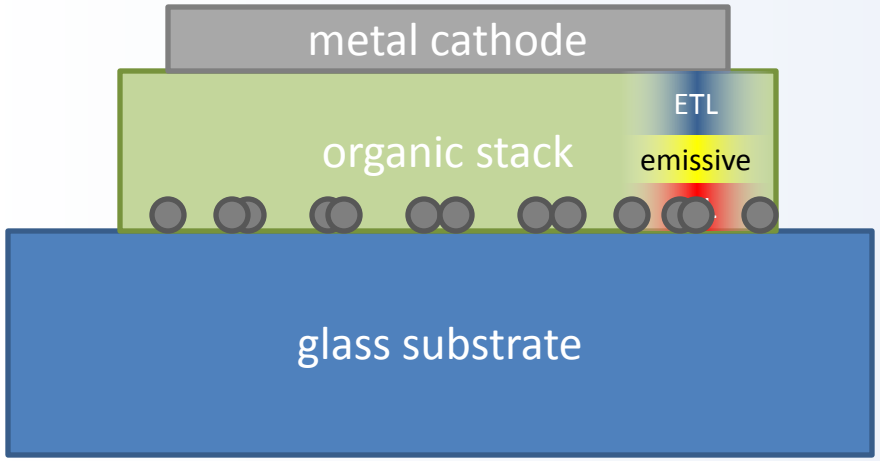
Internal Outcoupling Technologies

- use of ITO alternatives: metallic nanowires



index of refraction
n = 1.7 … 1.85

n = 1.5

"bottom emitting structure"

- elimination of the high-index ITO layer
- no significant efficiency increase, but freedom to develop new structures
  - process temperature to form effective network 140 ^{o}C
  - option of depositing conductive layer on top of other material

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Cathode Outcoupling Technologies

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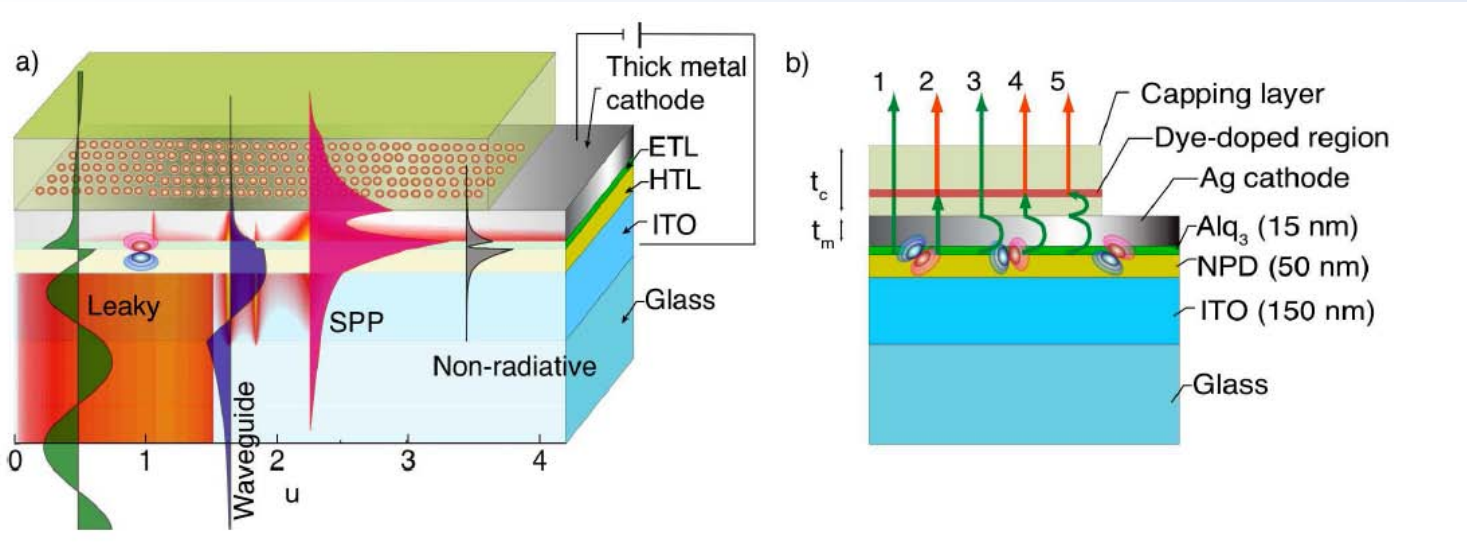
Cathode Outcoupling Technologies

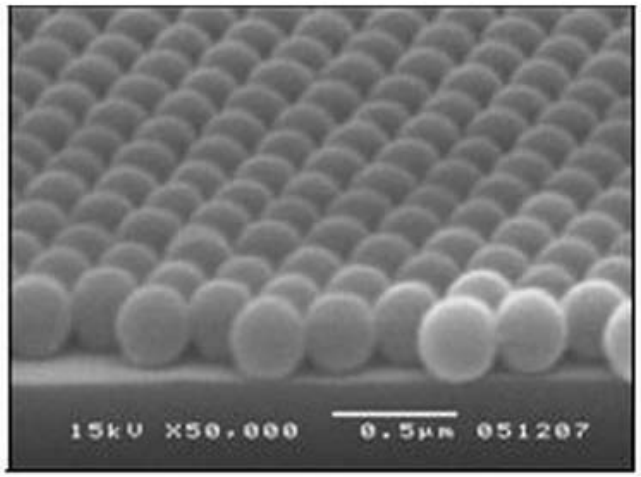
- surface plasmon polaritons
  - loss mechanism: coupling of exciton radiative energy in non-radiative surface plasmon
  - application of patterned surface to recover energy
  - resonant coupling with lumophore

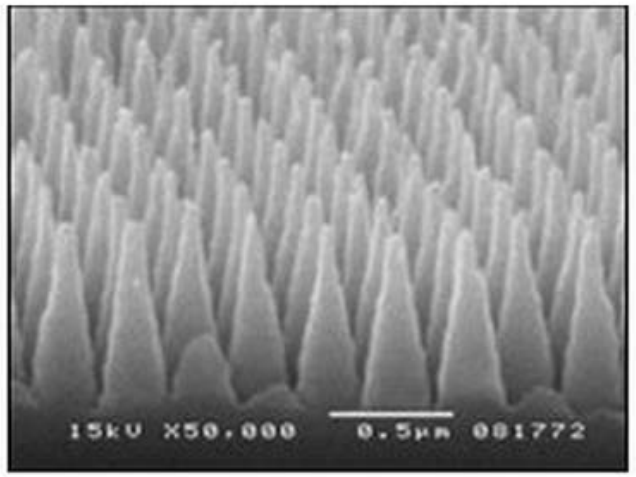


source: An et al., Optics Express 8 (5), p 4041 (2010)

Cathode Outcoupling Technologies

- Oji Paper
  - use of microstructures on metal cathode
  - no further details on device structure available
  - reported gains of 100%





source: Oji Paper (link: www.oled-info.com/new-microfabrication-technology-can-enhance-oled-light-extraction-efficiency)

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Pros & Cons

Technology	Pros	Cons
External Outcoupling	**simple technology compared to internal light extraction layers**	**only substrate modes are being extracted**
high-index glass	easy solution	high cost
microlens array		expensive patterning process
Brightness Enhancement Film	established technology, easy processing	quite costly
Internal Outcoupling	**organic / ito mode is being extracted**	**more complicated due to impact on device structure**
low-index grid	high impact on efficiency	SiO2 deposition and patterning layer
patterned ITO	no additional layers	requires ITO patterning, increases ITO sheet resistance
evaporated scattering layer		possible impact on device performance due to material system
buckles	high impact on efficiency	PDMS imprinting technology not scalable
scattering layer underneath ITO	high impact on efficiency	ITO deposition on top of scattering layer difficult
SSP harvesting		not mature technology yet, but very interesting

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