Enhanced Light Outcoupling from OLEDs Fabricated on Novel Low-Cost Patterned Plastic Substrates of Varying Periodicity

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Objectives

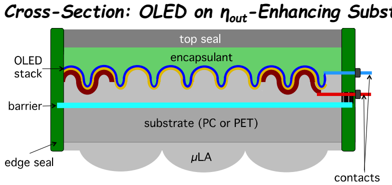
- Demonstrate that phosphorescent OLEDs fabricated on a low-cost light extraction substrate can approach DOE's SSL 2020 target of η_{out} = 70%.
- The principle: increase the outcoupling by disrupting surface plasmon excitation and internal waveguiding losses using unique corrugated integrated substrates with periodic or multiple-period design.
- Integration: top corrugation, metal mesh, and an air-side microlens array

R2R Process for Integrated η_{out}-Enhancing Substrates for OLED SSL (MCI)

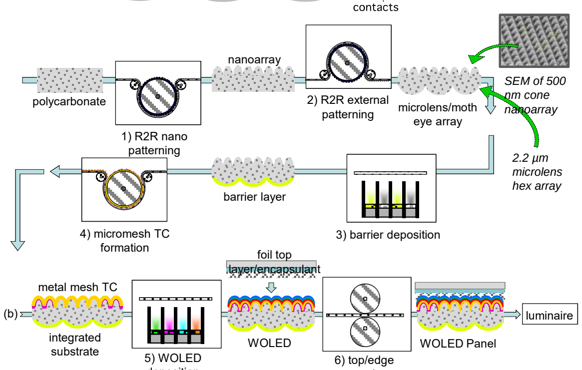
MCI is developing a low-cost R2R process for manufacturing integrated, η_{out}-enhancing OLED substrates for SSL with designs based on modeling and experiments performed at ISU.

- Cost-effective proprietary R2R manufacturing
- Large area patterned flexible integrated substrates
- Scalable for high volume, rapid production
- Multi-level structures: nano- or micro-pattern + high-conductivity embedded metal mesh TC/ITO + microlens array
- Easily patterned polycarbonate (PC) by direct molding at room temp
- Versatile process, amenable to a variety of structures and substrates
- Compatible with thermally evaporated OLED stack

Cross-Section: OLED on η_{out}-Enhancing Substrate



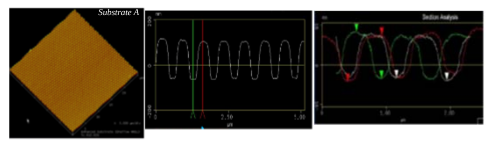
Plastic substrate with external barrier coating, top encapsulated and edge sealed



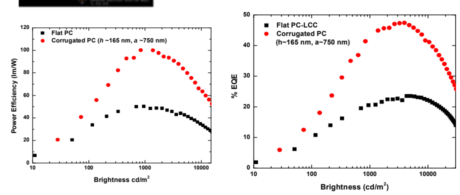
R2R production of an integrated OLED substrate. Top: PC is directly imprinted on both sides + an external barrier. (b) OLED deposition & encapsulation steps. (not to scale)

OLEDs (ISU)

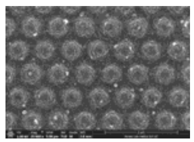
PC Substrates (pattern height: *h* <200 nm; pitch *a* ~750 or ~410 nm)
Achieved EQE ~56.5% for green PhOLEDs + blue & white OLEDs enhancement.



AFM image, section analysis, and green OLED attributes. Substrate: patterned PC with *h* ~165 nm; *a* ~750 nm.

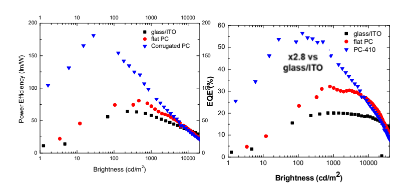


Device structure: PC/anode/HAT-CN (5 nm)/10% MoOx:TAPC (60 nm)/TAPC (20 nm)/6% $Ir(ppy)_3$:mCP (20 nm)/ TmPyPb (20 nm)/20% CsF:TmPyPb (40 nm)/ LiF (1 nm)/Al (100 nm)



FIB/SEM images of the complete OLED stack (top left), the ~40 nm corrugation at the Al layer (top center), AFM image (top right), and SEM of the top device (bottom) on PC with *h* ~165 and *a* ~740 nm. Observation: gradual reduction in *h* across the OLED stack, though still EQE ~50%.

Peak efficiency enhancements: 2-2.2x *vs* device on flat PC; luminous efficiency 170 cd/A, power efficiency ~100 lm/W, EQE ~50%.

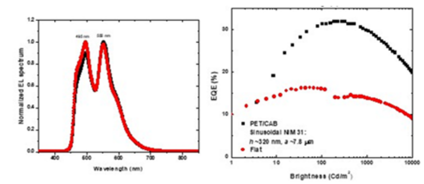


Power efficiency & EQE of green OLEDs on patterned & flat PC/PEDOT:PSS, & glass/ITO. Pattern features: were *a* ~410 nm, *h* ~190 nm.

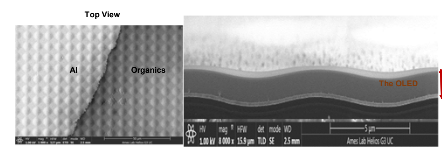
Peak efficiency enhancement: 2.8x *vs* device on glass/ITO. Luminous efficiency 206 cd/A, power efficiency 180 lm/W), EQE 56.5%.

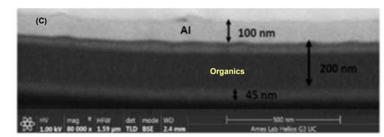
Micro-patterned PET/CAB Substrate (*h* ~320 nm; *a* ~7.8 µm)

Achieved EQE ~33% for white OLEDs; x2 enhancement *vs* OLED on flat PET/CAB.



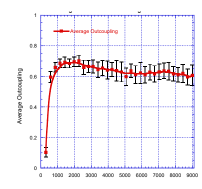
Device structure: PET/CAB/PEDOT:PSS/HAT-CN (5 nm)/10% MoOx:TAPC (120 nm)/TAPC (20 nm)/8 % FIrpic:mCP (19 nm)/6 % PO-01:mCP (1 nm)/TmPyPb (20 nm)/20% CsF:TmPyPb (40 nm)/LiF (1 nm)/Al (100 nm)





FIB/SEM images of a fully conformal WOLED; EQE ~33%, 2x enhancement.

Modelling (ISU)



Simulated outcoupling from conformally corrugated OLEDs on PC as a function of the pitch for a corrugation height of 300 nm and HTL of 140 nm. Rigorous scattering matrix simulations were utilized. At each pitch an average is taken over a small range of ETL thicknesses from 55 to 65 nm.

Concluding Remarks

- We achieved EQE ~56.5% for green PhOLEDs, ~33% for white & blue devices (>x2 enhancements) by using :

1) Periodic smooth nano- or micro-patterned substrates to extract light trapped in the anode+organics and photons lost to surface plasmon excitation.
2) Devices with low *h* and in particular with additionally low *a* showed reduced corrugation across the stack, though still significant enhancements.
3) Fully conformal enhanced white OLEDs were obtained on micro-patterned PET/CAB.

- We modeled patterned OLEDs achieving agreement with experiment.

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