Optics and Photonics Congress 2024

Near-planar light outcoupling structure for ultra-efficient organic light-emitting diodes

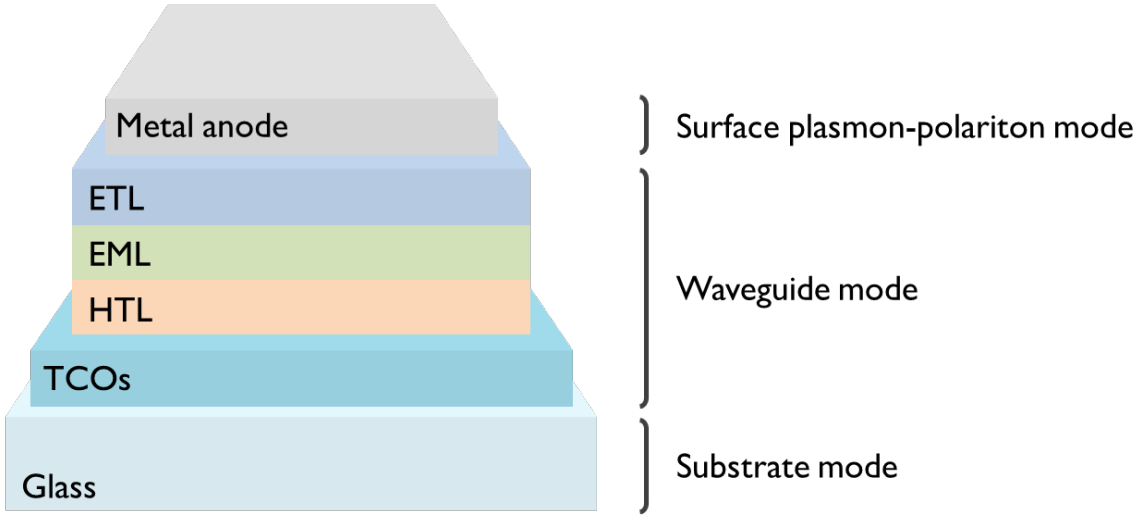
MinJae Kim[1], Junho Kim[2], and Seunghyup Yoo[2*]

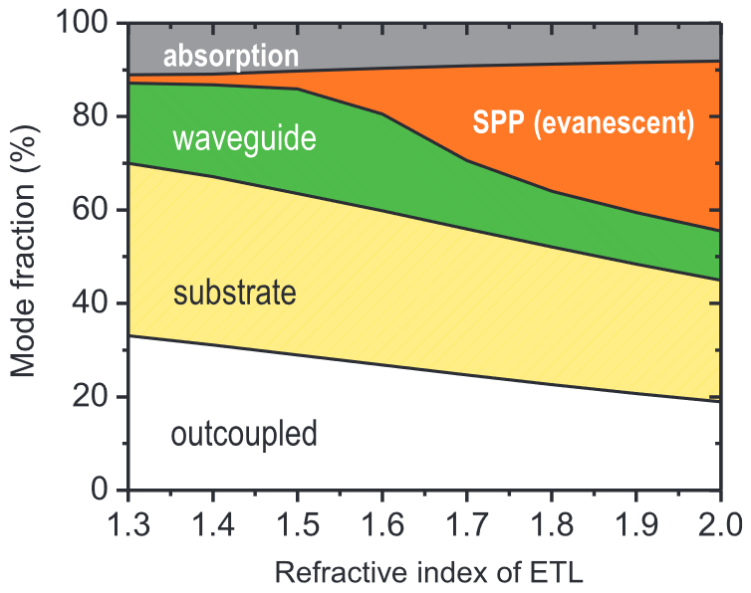
[1]Department of Materials Science and Engineering, KAIST

[2]School of Electrical Engineering, KAIST

*E-mail: mj3259@kaist.ac.kr, *Corresponding: syoo_ee@kaist.ac.kr*

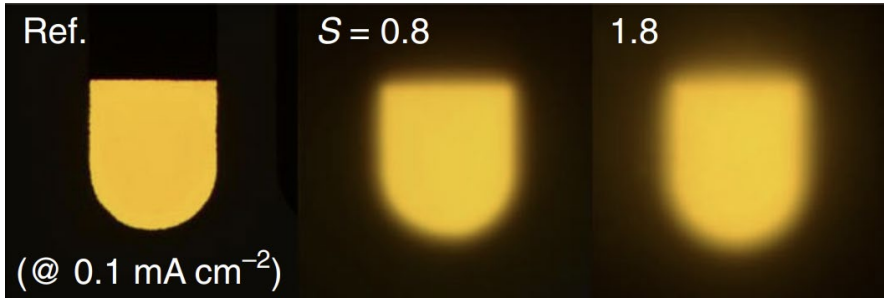
Loss channels in OLEDs



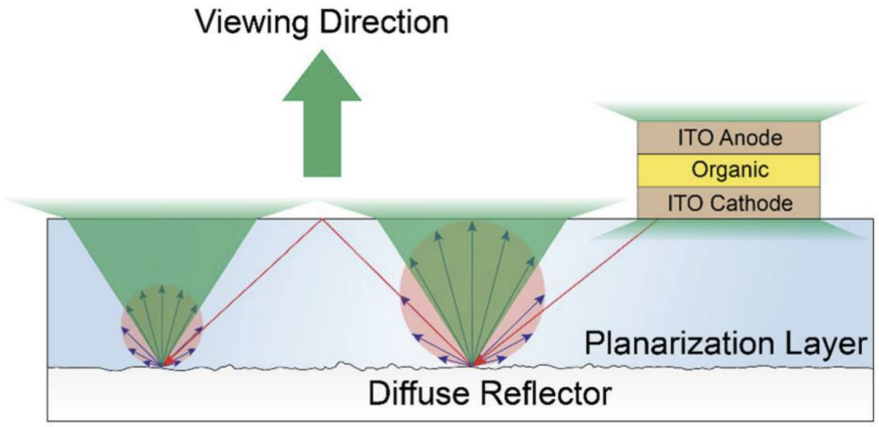


- Various strategies, including corrugation, low-index materials, and deliberate photonic design, have been applied to alleviate the SPP and waveguide modes.
- However, such strategies unload the dissipation intensity to substrate mode, thereby rendering effective substrate mode outcoupling methods imperative.

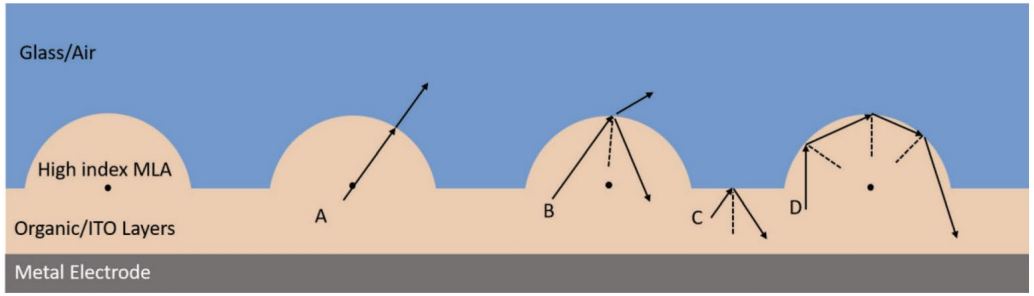
Current focus of light outcoupling strategies



Nat. Commun. 9.1 (2018): 3207.



ACS Photonics 2018, 5, 3315−3321

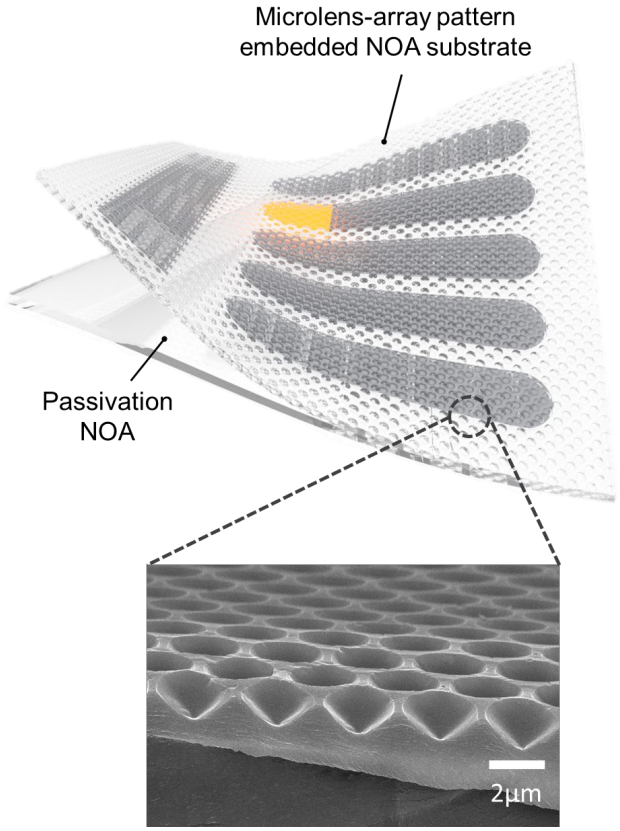


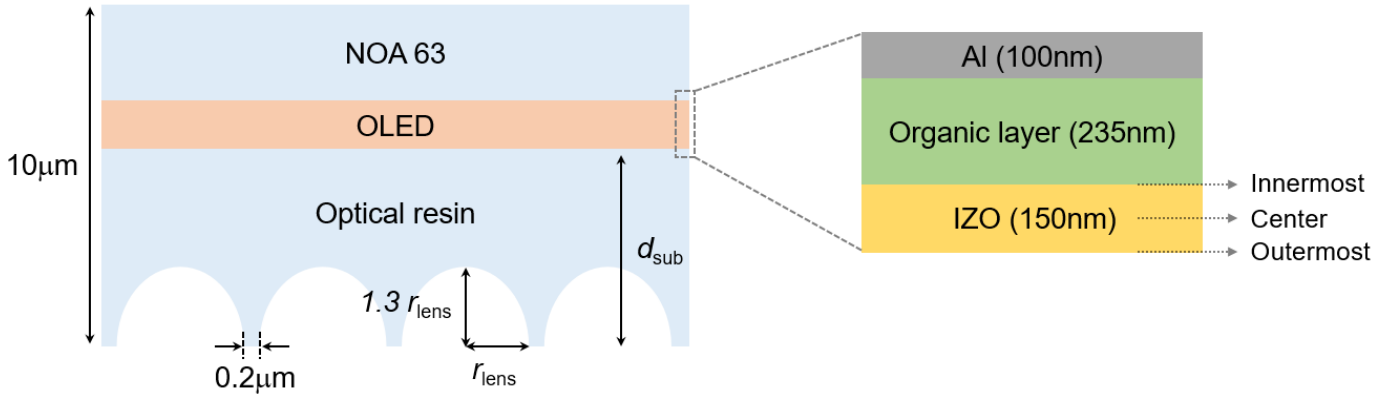
Adv. Funct. Mater. 2019, 29, 1808803

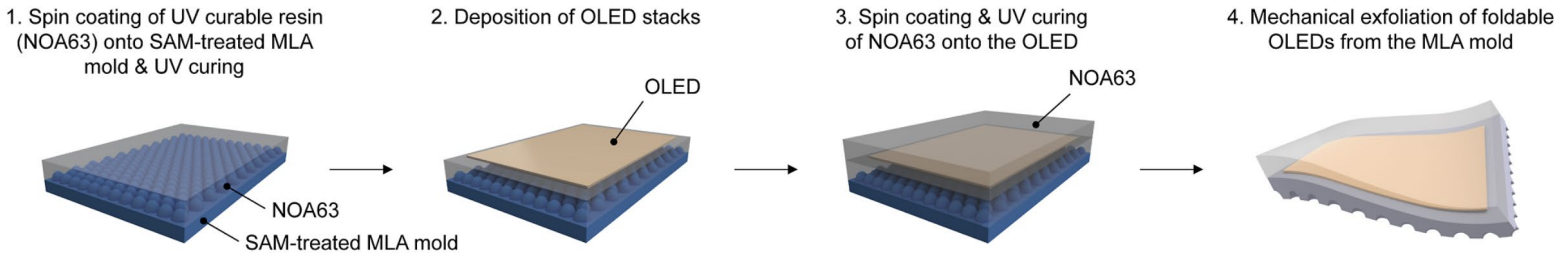
Despite vast attention devoted to light extraction efficiency and blurring, the thickness and rigidity of the outcoupling structure have been marginalized.

Ultrathin inverted microlens array

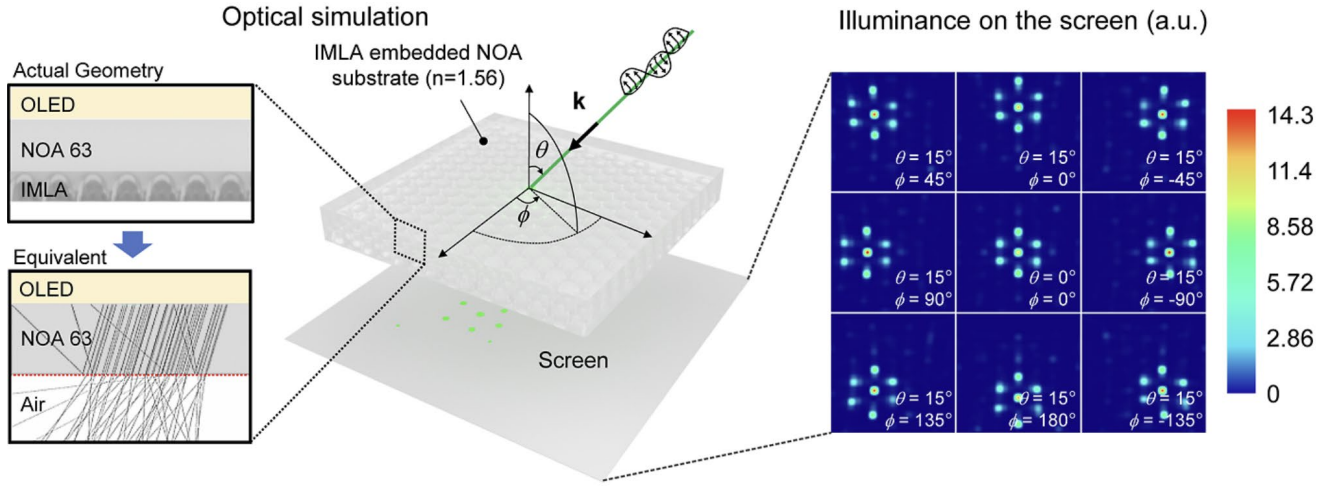
Fabrication

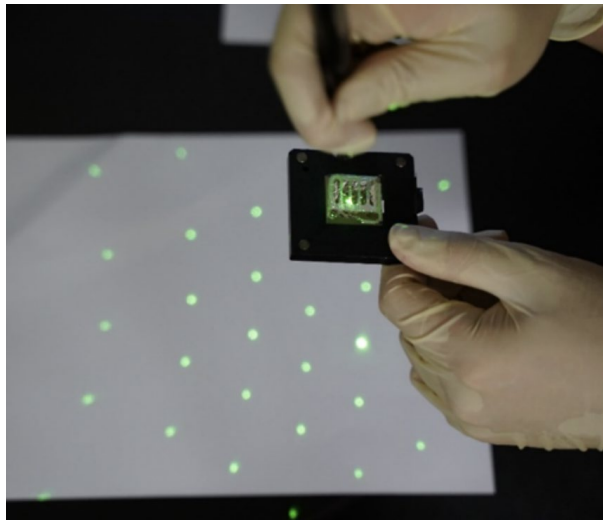






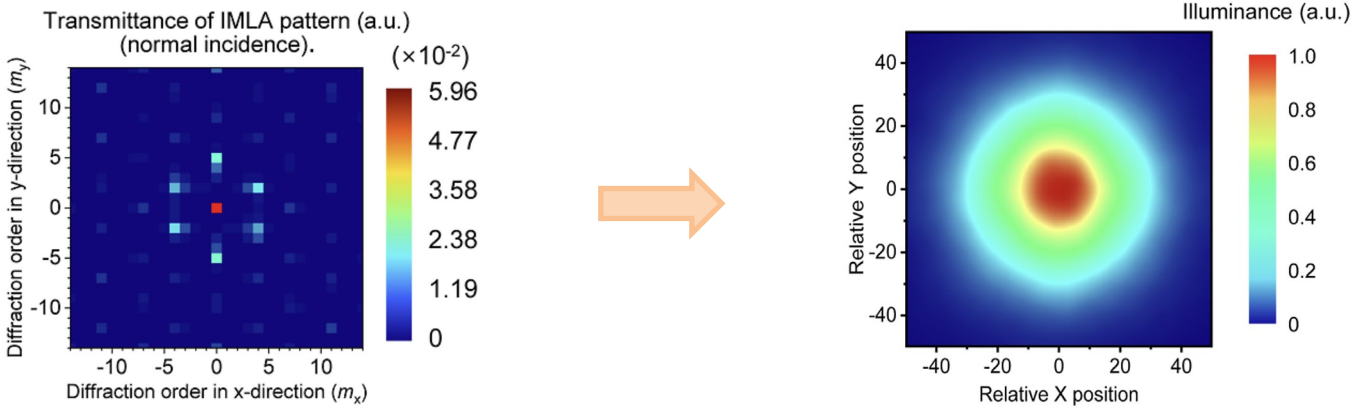
Potential optical diffraction artifacts



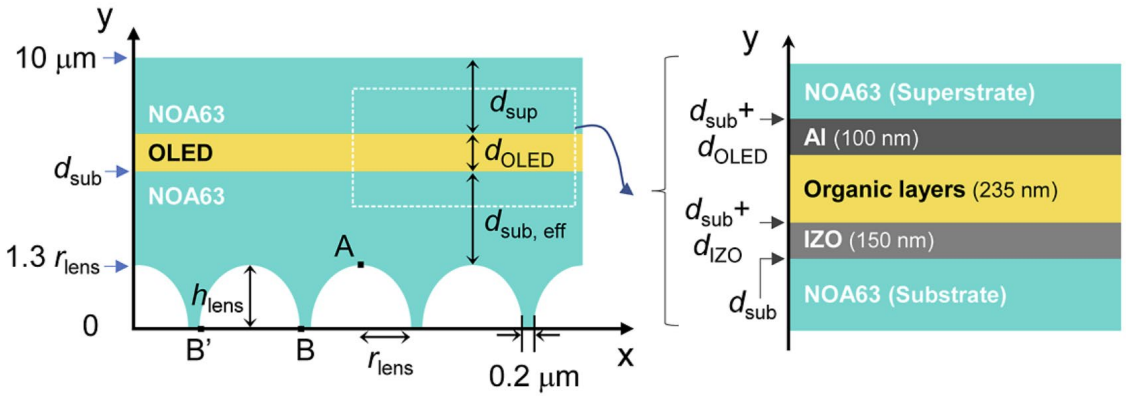


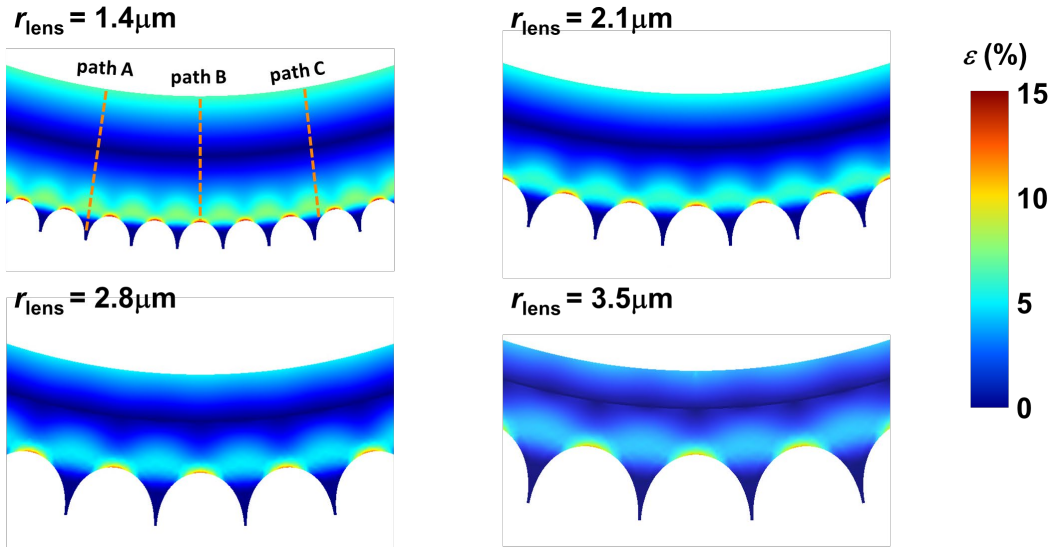
In the far-field diffraction regime (Fraunhoffer diffraction)

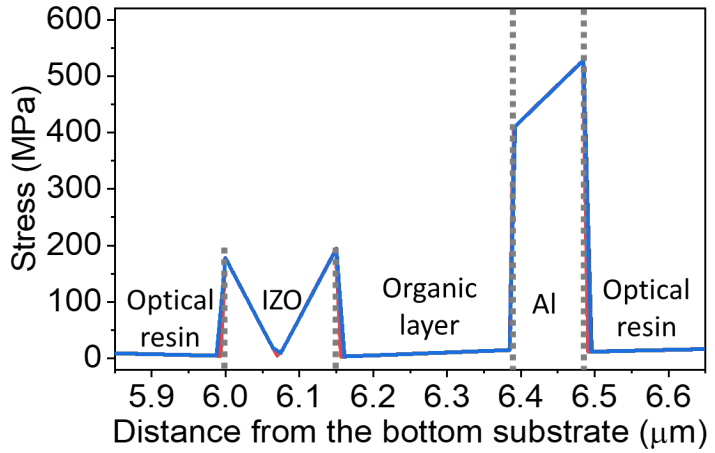
$$I_{out}(k_x, k_y) = |\mathcal{F}(I_{inc}(x,y) \cdot T(x,y))|^2$$



Mechanical performances

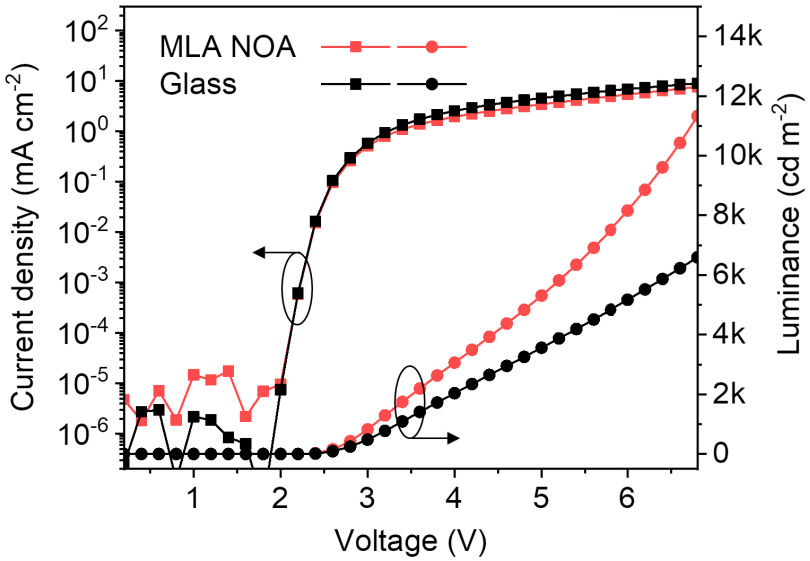


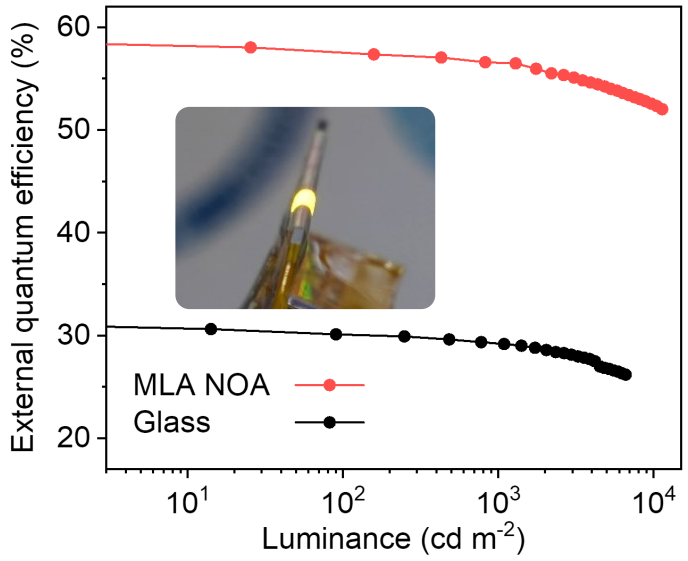




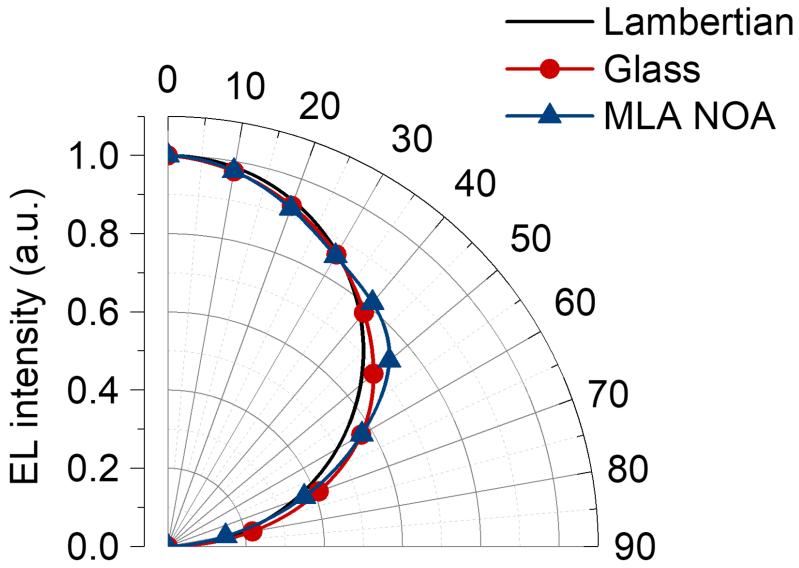
- Stress imparted to the brittle IZO layer was minimized by the Euler-Bernoulli bending theory.
- Through the deliberate mechanical design, we enable ultrathin, highly flexible, and ultra-efficient OLEDs.

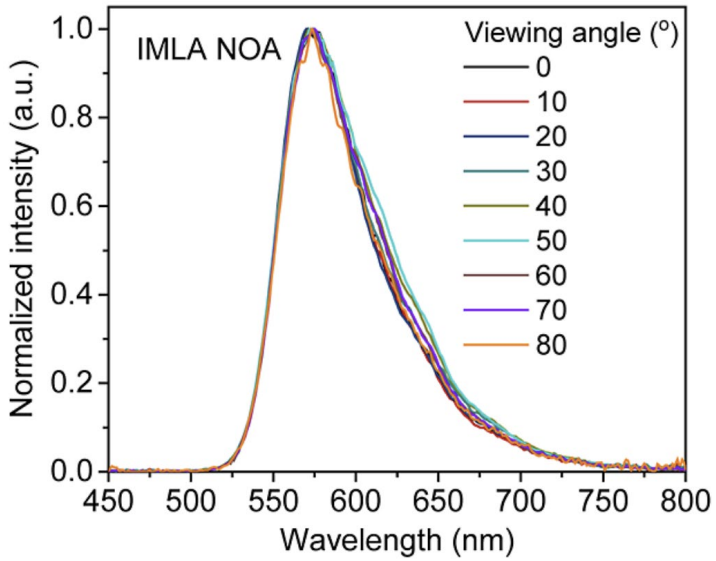
Device performances



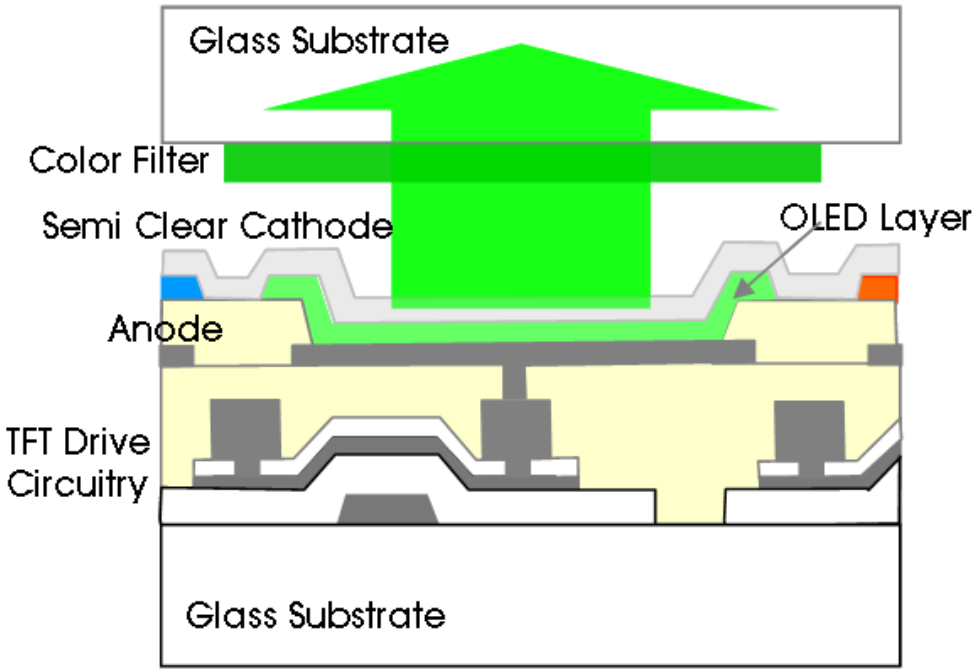


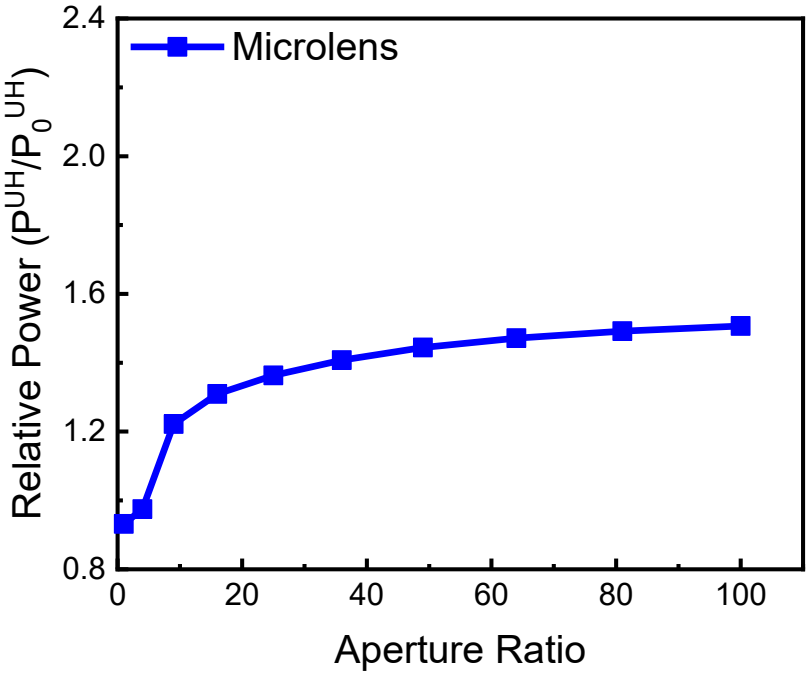
- High EQE (58%)
- Ultrathin form factor
- Flexibility ($R = 50\mu m$)
- Near-Lambertian emission pattern
- Tolerance to viewing angle-dependent color change





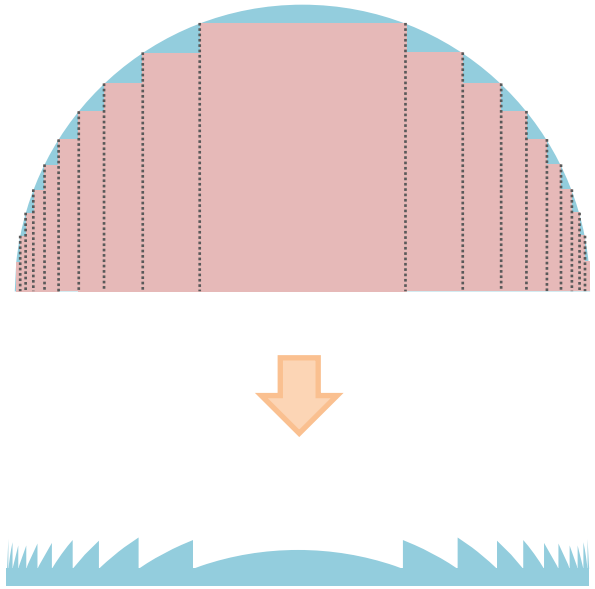
Limitations



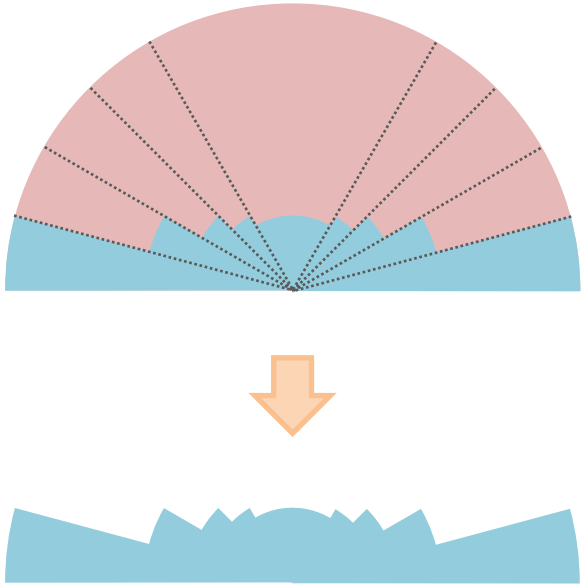


- On-pixel outcoupling structure is imperative for display applications
- Ultra-efficient low-angle emission is a crucial factor in the realization of high-luminance displays

Radial reduction



Fresnel lens

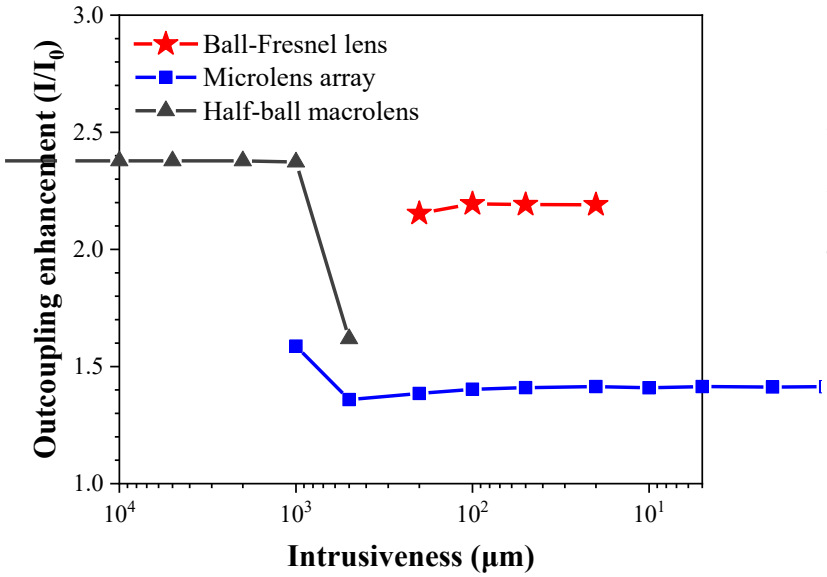


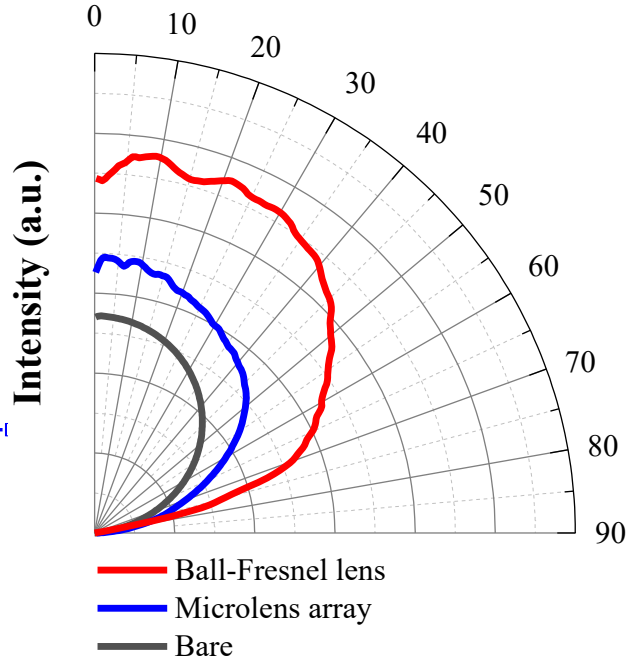
Ball-Fresnel lens

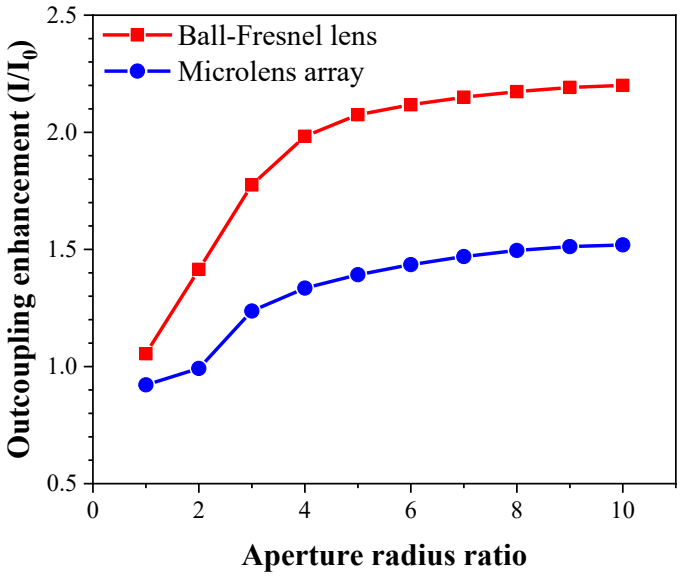
Inspired by the Fresnel lens, we propose radial reduction of the half-ball lens

On-pixel outcoupling enhancement

A near-planar light outcoupling structures for ultra-efficient organic light-emitting diodes available!







Conclusion

- Two factors heretofore underrated, thickness and aperture ratio, are taken into account for outcoupling enhancement in display applications.
  - Ultrathin and foldable outcoupling structure could be enabled with an inverted microlens array
  - On-pixel outcoupling enhancement could be realized with Ball-Fresnel lens
- Both low-angle emission and EQE were greatly enhanced by the use of Ball-Fresnel lens.

Thank you for your attention

MinJae Kim[1], Junho Kim[2], and Seunghyup Yoo[2]*

[1] Department of Materials Science and Engineering, KAIST

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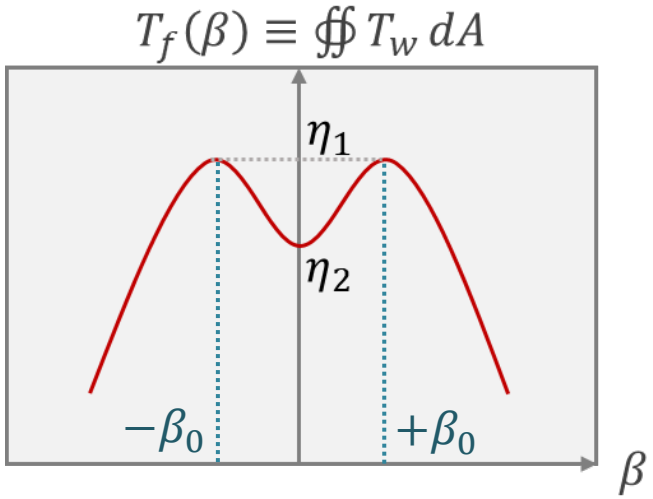
Appendix: Symmetry inheritance theorem

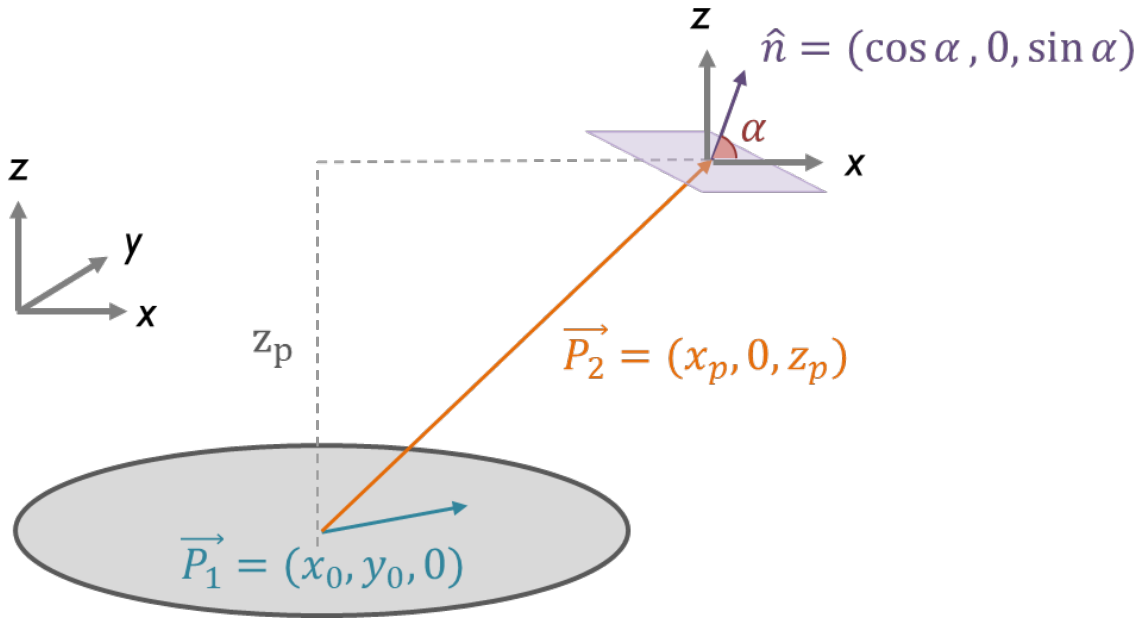
Theorem. Provided an OLED with C_n symmetry, the optimal structure should also inherit the C_n symmetry

Corollary. For a circular OLED, the optimal structure should have circular symmetry



Even with the postulate of $\eta_1 > \eta_2$, it all boils down to $\eta_1 = \eta_2$

(i.e. $\beta_0 \to 0$)



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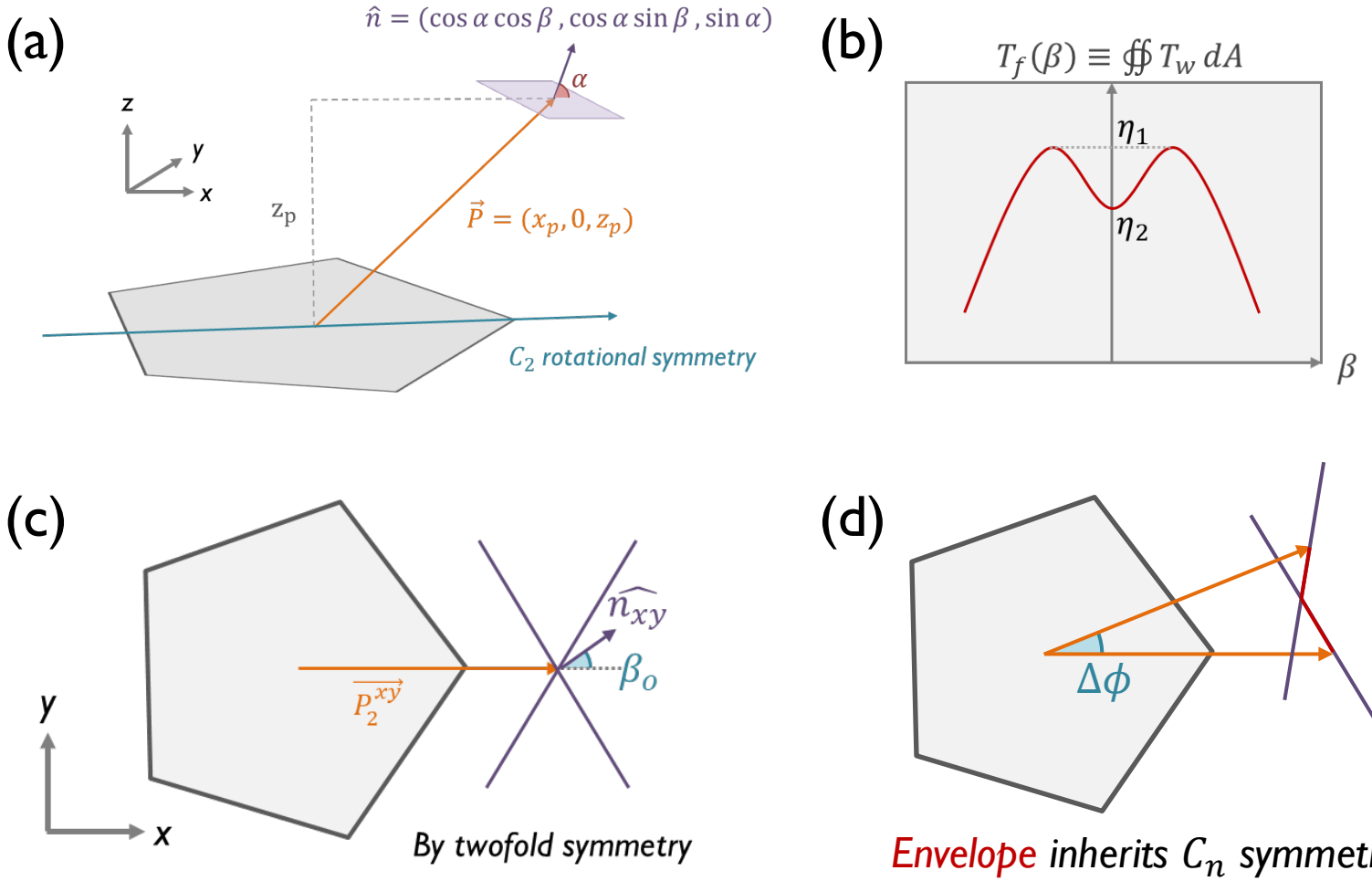
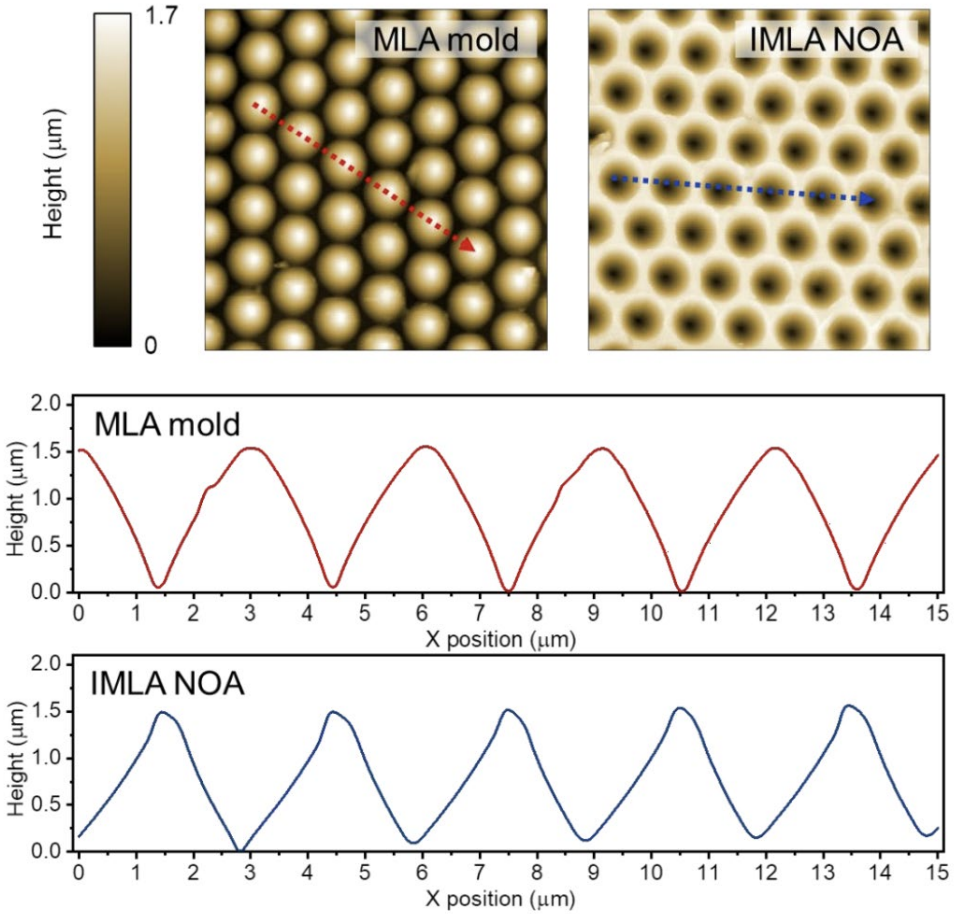
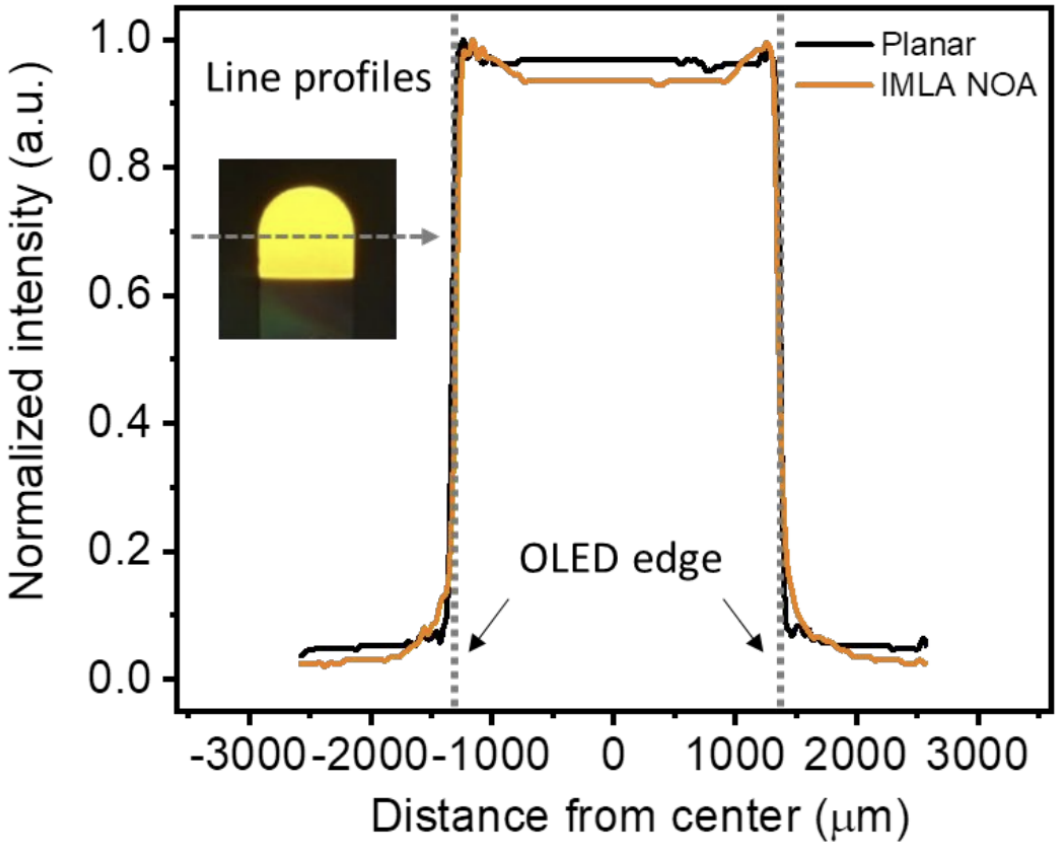
Proof.



Appendix: Inverted microlens array





Appendix: Mechanical scrutinization