(Supporting Information)

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A Morphological Study of Random Nanostructured External Light Extraction Layers for Enhancing Optical Characteristics of OLEDs

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1. **EL characteristics of fluorescence OLED according to O_2 plasma treatment time at an initial thickness of 1500nm, 4500nm, 9500nm, and 14500 nm**

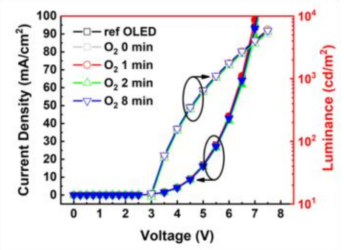
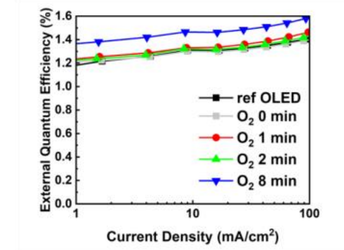
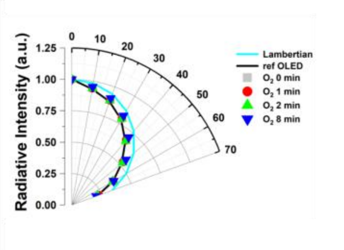
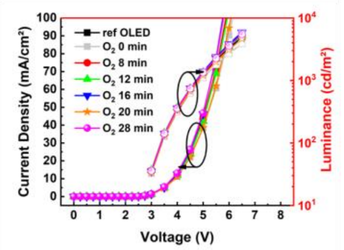
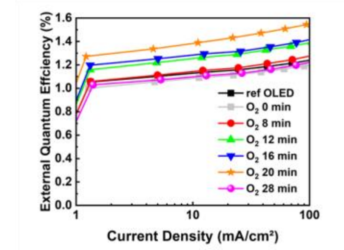
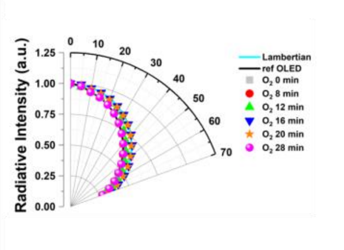
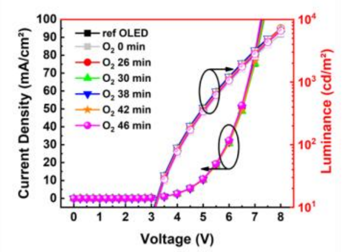
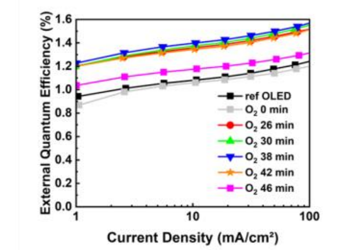
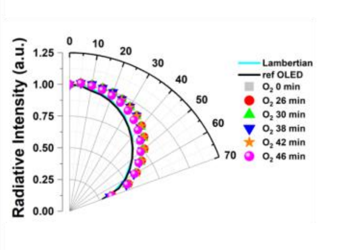
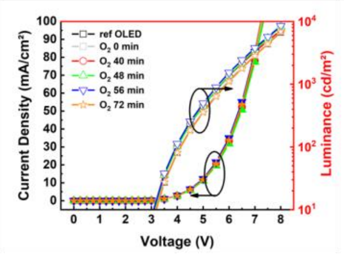
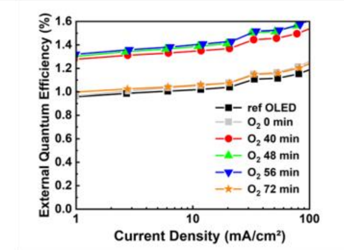
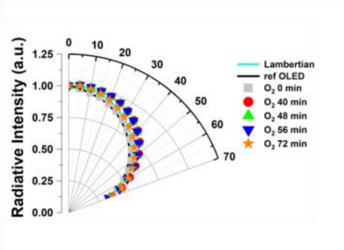
SU-8 initial thickness	Current density - Voltage - Luminance	Current Density - External Quantum Efficiency	View angle ratio
1500 nm			
4500nm			
9500nm			
14500nm			

Fig. S1 Comparison of luminous efficiency of RNPS fabricated by varying the O_2 plasma treatment time according to the initial thickness of each SU-8 applied to OLED.

The device's electrical characteristics with and without the RNPS were almost identical since they were placed, where they do not affect the devices (current density-voltage characteristics of devices). The OLEDs with the RNPSs exhibited higher efficiencies than those without the RNPSs in terms of overall current density. For the case of an initial thickness of 1500 nm, the OLED treated with oxygen plasma for 8 minutes exhibited a maximum external quantum efficiency (EQE) of 1.47% at 20 mA/cm², while the reference device had an EQE of 1.31% at the same current density. The enhancement in EQE at 20 mA/cm² was 1.12 times in the normal direction. When the initial thickness was 4500 nm, the OLED treated with oxygen plasma for 20 minutes showed a maximum EQE of 1.42% at 20 mA/cm², whereas the reference device exhibited an EQE of 1.15% at the same current density. The enhancement in EQE at 20 mA/cm² was 1.24 times in the normal direction. In the case of an initial thickness of 9500 nm, the OLED treated with oxygen plasma for 38 minutes displayed a maximum EQE of 1.43% at 20 mA/cm², while the reference device had an EQE of 1.11% at the same current density. The enhancement in EQE at 20 mA/cm^2 was 1.29 times in the normal direction. Lastly, for an initial thickness of 14500 nm, the OLED treated with oxygen plasma for 56 minutes exhibited a maximum EQE of 1.43% at 20 mA/cm^2, while the reference device had an EQE of 1.05% at the same current density. The enhancement in EQE at 20 mA/cm^2 was 1.36 times in the normal direction. Please note that these measurements were conducted in the normal direction, and the enhancements in EQE represent the improvements achieved through the application of oxygen plasma treatment for different durations at various initial thicknesses. When the critical O_2 plasma treatment time is reached, the maximum EQE is achieved, indicating an optimized plane structure ratio. On the other hand, when the O2 plasma treatment time exceeds the critical point, the EQE sharply decreases. This is explained by a rapid decrease in the density of nano-pillars or the disappearance of the plane structure, leading to a loss of the light extraction film's functionality. Furthermore, it is observed that as the initial thickness of SU-8 increases, the enhancement becomes higher. As the thickness of the lower layer approaches zero, light is refracted backward within the lower layer structure and exits towards the substrate, resulting in higher light extraction efficiency. Additionally, the thicker the nano-pillar structure, the stronger the directionality of light extraction towards the upper nano-pillars. Therefore, it was confirmed that the efficiency and viewing angle improved by reducing the loss of the substrate mode based on the scattering characteristics of the RNPSs.

2. **Perpendicular transmittance and Diffuse Transmittance as functions of the visible wavelength of MLA, Non-patterned SU-8, and different RNPSs**.

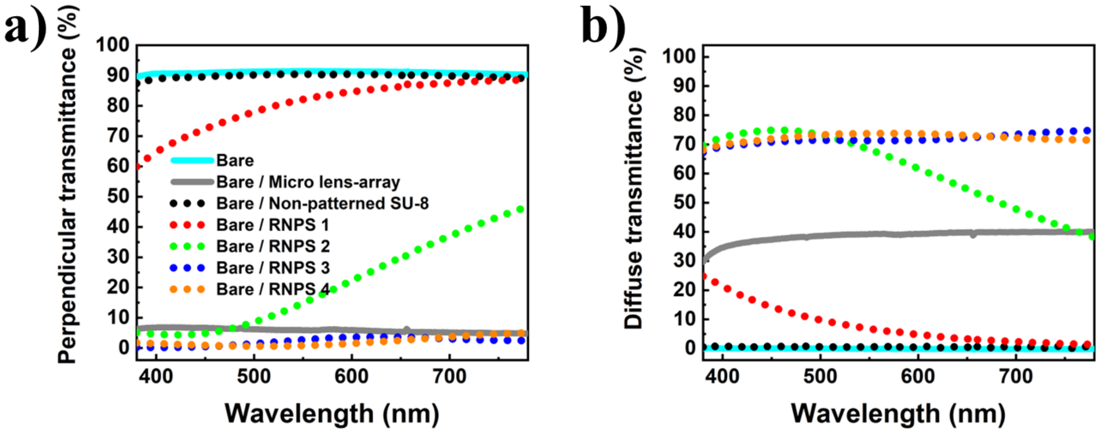


Fig. S2 (a) Perpendicular transmittance and (b) Diffuse Transmittance as functions of the visible wavelength of MLA, Non-patterned SU-8, and different RNPSs. All samples are formed on a bare substrate (soda-lime glass).

Fig. S2 presents the perpendicular transmittance and diffuse transmittance of RNPS and MLA with optimized plane structure ratios obtained from non-patterned SU-8 films of various thicknesses. All samples were fabricated on bare soda-lime glass substrates. The MLA composed of micro-patterns exhibited a perpendicular transmittance of ~10% and a diffuse transmittance of ~40% in the visible range. The non-patterned SU-8 film has a very low measured diffuse transmittance of less than 1% and thus results in low haze over the entire wavelength range. As the thickness of the nanopillar increases, the diffuse transmittance of RNPS exhibits a marked increase over the entire spectrum. At a wavelength of 550 nm, RNPS 4 achieves a maximum diffuse transmittance of about 70%. The haze calculated from the transmittance with the nanopillar covers a broad spectral range that correlates with increasing nanopillar height and density. Therefore, RNPS was considered a suitable film for light extraction while minimizing optical losses through absorption and scattering.