Significant Light Extraction Enhancement of Organic Light-Emitting Diodes Using Embedded High-index Deep-Groove Dielectric Nanomesh Fabricated by Large-area Nanoimprint

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Nano/micro-structure patterned dielectric structures are one of the most promising ways to increase light extraction efficiency of light-emitting devices. The tiny structures on the substrate release the light trapped in substrate and waveguide modes into air by scattering. To achieve high light extraction enhancement, the nano/micro structures must have enough heights (from several hundred nanometers to one micron) so that they can efficiently scatter the light. However, for organic light-emitting diodes (OLEDs), the thin organic light-emitting layers (~100nm) cannot sustain such large surface roughness[1]. To solve this conflict, here, we report a new OELD structure, named high-index deep-groove dielectric-nanomesh OLED (HDNM-OLED) that has a nanopatterned substrate embedded with a high-index deep-groove (300nm) nanomesh and capped with a low-index planarization layer, which significantly enhances the light extraction without electrical degrade and have achieved the highest EQE for the given organic light emitting material.

The new HDNM-OLED structure comprises a nanomesh pattern on a glass substrate, a high-index deep-groove (300nm) nanomesh on top, a top planarization layer that planarizes the nanomesh, and then other OLED materials (ITO/NPB/TCTA/CBP: $Ir(piq)_3$/TPBI/LiF/Al). The nanomesh has a 400nm-pitch square lattice with square-hole arrays. The high-index material is Ta_2O_5 and has an index of 2.2. The line width of the nanomesh is 130nm and the groove depth is 300nm. In fabrication, a Cr nanomesh was first patterned on glass substrate by large-area nanoimprint[2, 3], Cr evaporation and lift-off. Then a nanomesh with 300nm groove depth was etched into the glass by RIE with the Cr mesh mask. After removing the Cr mask, 400nm-thick high-index material Ta_2O_5 was deposited on top by e-beam evaporation followed by spin-coating a 500nm-thick spin-on-glass as a planarization layer. Then, 100 nm ITO, 140 nm-total-thickness green light emitting active layers and LiF (0.5nm)/Al (100nm) back electrode were sequentially thermally evaporated on top of it to form the final OLED device (Figure 1a).

Compared with the conventional planar ITO-OLEDs, the OLEDs with a high-index deep-groove-depth nanomesh expreimentally achieved 1.71 fold total front surface EL enhancement and 1.74 fold maximum EQE enhancement increasing from 27% to 48% (Figure 2), which we believe is the highest EQE achieved to date for green phosphoresvcent OELDs using the same light mission layer (CBP:$Ir(piq)_3$) .

The new OLED structure using a novel nanopatterned substrate embedding a high-index deep-groove–depth nanomesh, with high light extraction enhancement and large-area nanoimprint fabrication process, overcomes the key limition of using nanopatternd substrates for increasing light extracton efficiency of OLEDs and offers new approaches for high performance OLEDs lighting and displays.

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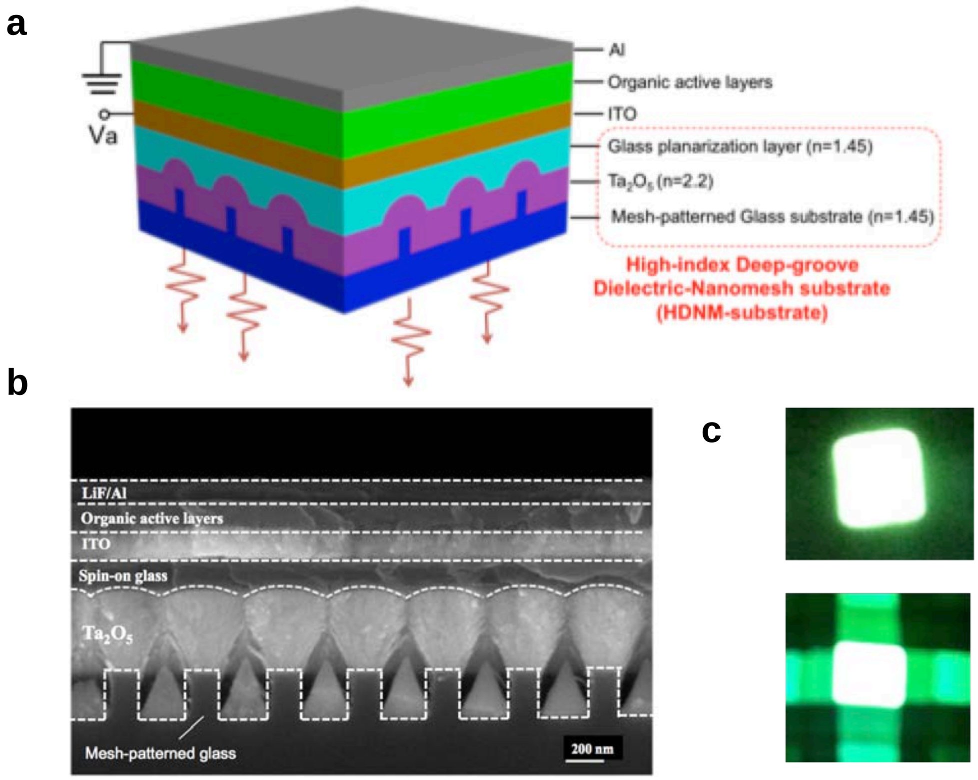

Figure 1: Organic Light Emitting Diode (OLED) with a nanopatterned substrate embedding a high-index deep-groove depth nanomesh (HDNM-OLED) (a) Structure scehmatic: a glass substrae with a high-index (n=2.2) deep-groove-depth nanomesh embedded, a top ITO anode, a back LiF/Al cathode, and in between green phosphorescent organic light-emitting active layers. (b) SEM image of the cross-section of the HDNM-OLED. (c) photography of light emission from the a fabricated OLED with nanomesh (bottom) and a conventional ITO-OLED (top).

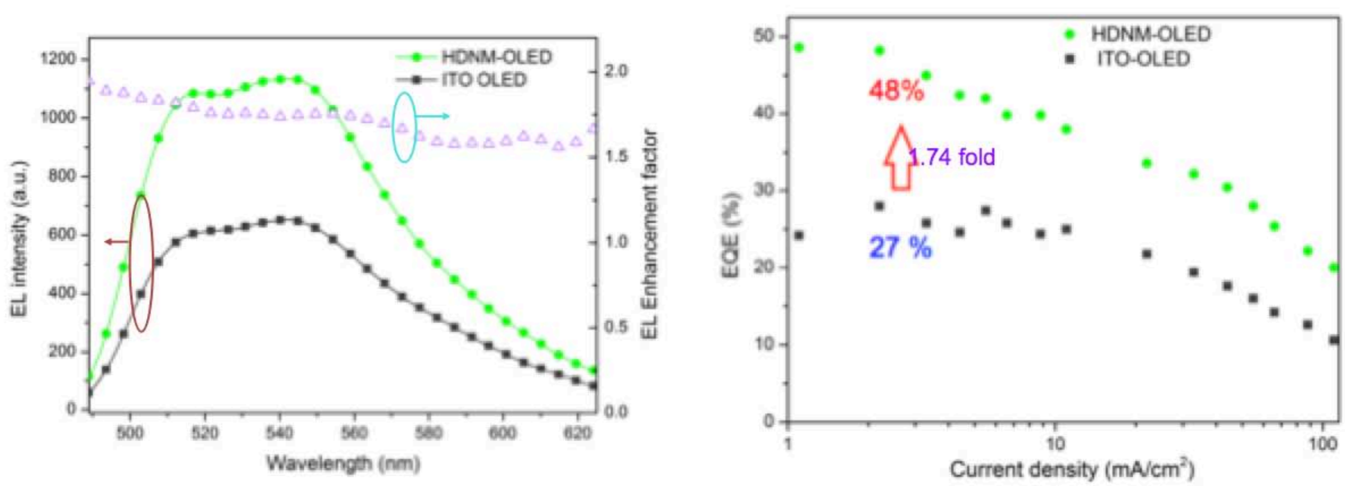

Figure 2: Electroluminescence (EL) spctrum and EQE of HDNM-OLEDs and ITO-OLEDs. (a) Total front surface EL spectrum of HDNM-OLEDs and ITO-OLEDs. HDNM-OLEDs showed an average 1.71 fold higher EL intensity higher than that of ITO-OLEDs. (b) EQE of HDNM-OLEDs and ITO-OLEDs. HDNM-OLEDs showed a maximum EQE of 48%, 1.74 fold higher than that of ITO-OLEDs.