Significantly-Enhanced Light Extraction and Power Efficiency of Red Organic Light-Emitting Diode by Nano-Mesh Fabricated by Large-Area Nanoimprint

Ji Qi, Wei Ding, Yuxuan Wang, Qi Zhang, Hao Chen and Stephen Y. Chou*
Nanostructure Laboratory, Department of Electrical Engineering
Princeton University, New Jersey, 08544

Red organic light-emitting diodes (OLEDs) are the key components in full-color OLED displays and withe OLED lighting. But compared with the green and blue OLEDs, to date the red OLEDs exhibit much lower quantum and power efficiencies, being a key limitation in the power dissipation of OLED displays[1] and lighting. Therefore, an improvement in red OLEDs performance is of great importance. Here, we report a new red OLED structure that uses a nano-mesh configuration which not only enhances the light extraction but also lowers the driving voltage, hence significantly enhancing quantum and power efficiencies.

The new red OLED structure uses a glass substrate with nano-mesh etched in it. By depositing sequentially the ITO (anode), the light emitting active layers (red phosphorescent host-guest system and electron/hole transport materials) and Al (cathodes) were on top of the glass, the entire LED materials have a nano-mesh configuration (Fig. 1a). The nano-mesh etched in the glass has a 400nm-pitch square lattice with square-hole arrays (Fig. 1b). The line width of the grating is 75nm and the etching depth was optimized to 40nm. The topology of the grating also modifies the materials deposited on top of it into nano-mesh configuration, although the modification gets weaker for layers further away from the etched glass surface.

In fabrication, a 400nm-pitch Cr mesh with subwavelength square-hole arrays was first patterned on glass substrate by large-area nanoimprint[2, 3], Cr evaporation and lift-off. Then the grating was etched into the glass by RIE with the Cr mesh mask. After removing the Cr mask, 100 nm ITO, 110 nm-total-thickness light emitting active layers and LiF (0.5nm)/Al (100nm) back electrode were thermally evaporated on the glass substrate embedded with nano-meshes to form the final red OLED device.

Compared with the conventional planar ITO-OLEDs, the red OLEDs with nano-mesh have achieved experimentally: (i) 33% maximum external quantum efficiency enhancement without lens (Fig. 2a); (ii) 150% maximum power efficiency enhancement at 6mA/cm^2 (Fig. 2b); (iii) 1.86 fold lower driving voltage at 6mA/cm^2 (Fig. 2c). We believe they are the highest power and quantum efficiencies enahncement factors achieved to date for red phosphosresent OLEDs.

The new nano-mesh red OLED structures, with high light extraction enhancement, low driving voltage, significantly enhanced power efficiency and large-area nanoimprint fabrication process offer new approaches for high performance OLEDs lighting and displays.

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*corresponding author: chou@princeton.edu

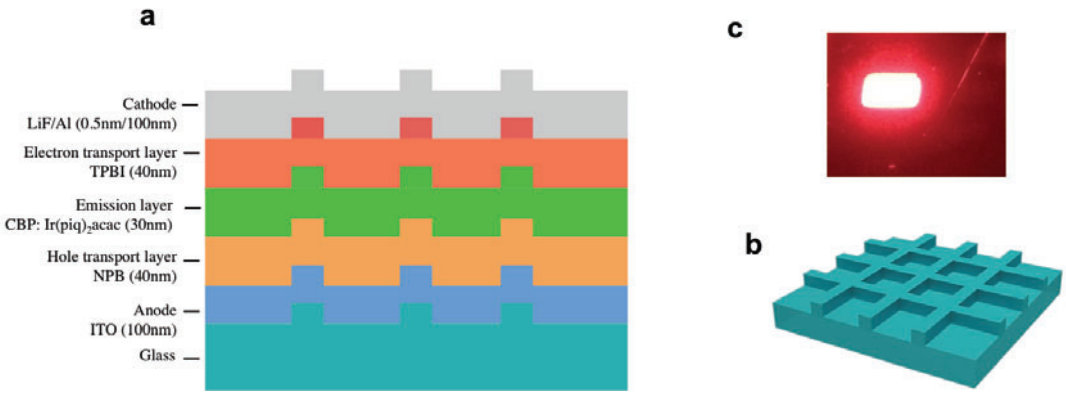

Figure 1: Red Organic Light Emitting Diode (OLED) with nanoplasmonic mesh. (a) Structure scehmatic: a glass substrae with a nanoplasmonic mesh embedded, a top ITO anode, a back LiF/Al cathode, and in between red phosphorescent organic light-emitting active layers. (b) glass substrate with a nanoplasmonic mesh embedded in it (c) photography of light emission from the fabricated red OLEDs with nanoplasmonic mesh.

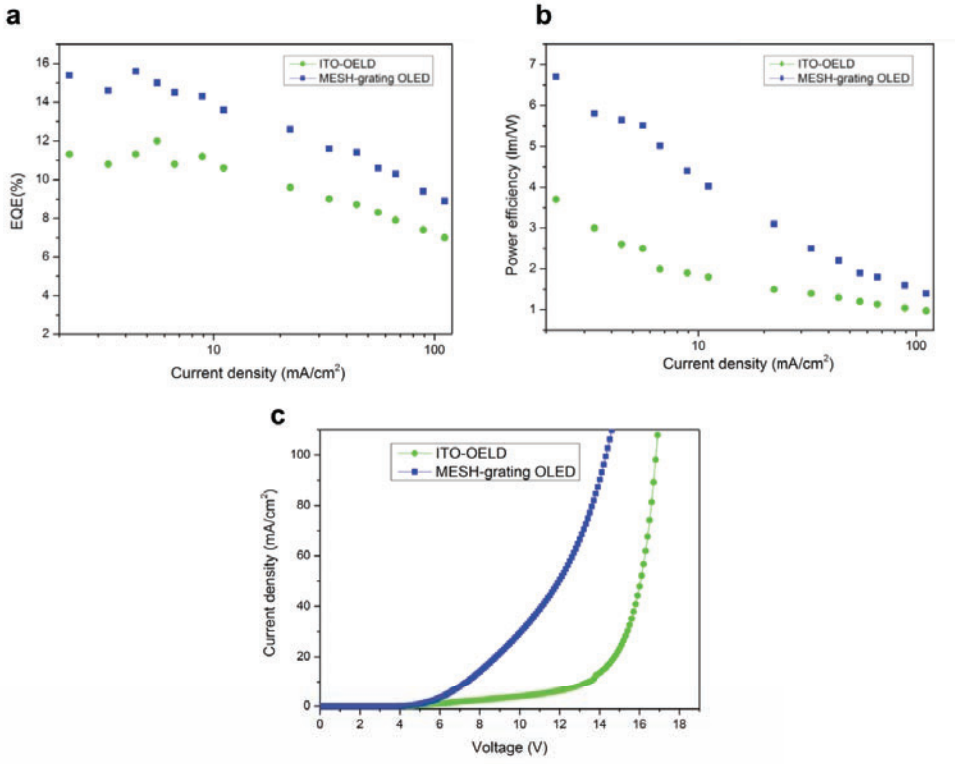

Figure 2: EQE, Power efficiency and J-V characterizations of nanoplasmonic mesh-OLEDs and ITO-OLEDs. (a) EQE of mesh-OLEDs and ITO-OLEDs. Mesh-OLEDs showed a maximum EQE of 15.6%, 1.33 fold higher than that of ITO-OLEDs. (b) Power efficiency of mesh-OLEDs and ITO-OLEDs. Mesh-OLED showed 2.5 fold higher power efficiency than ITO-OLEDs at 6mA/cm^2. (c) Current density of mesh-OLEDs and ITO-OLEDs versus voltage. At 6mA/cm^2, mesh-OLEDs showed 1.86 fold lower driving voltage compared with ITO-OLEDs.