New Plasmonic Nanocavity Organic Light-Emitting Diode with Significantly Enhanced Light Extraction, Contrast, Viewing Angle, Brightness and Low-Glare

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One central challenge in light emitting diodes (LEDs) is to increase light extraction[1,2]; but for display applications, other factors may have equal significance, such as ambient light absorption, contrast, viewing angle, brightness and low-glare[3]. However, current LED structures enhance only some of the factors, often at the expense of degrading the others. Here, we report a new organic LED structure that uses a novel plasmonic nanocavity, termed "plasmonic cavity with subwavelength hole-array" (PlaCSH), and can significantly enhance all the above factors with unprecedented performances[4].

The PlaCSH-OLED has a novel plasmonic nanocavity, PlaCSH, that comprises a top light-transmissive metallic-mesh electrode with subwavelength hole-array (MESH) as one of two cladding layers of the plasmonic cavity, a planar opaque metallic back electrode as another cladding layer, and in between light emitting materials (green phosphorescent host–guest materials) (Fig. 1a).

Compared to the conventional OLEDs (the same but without PlaCSH), PlaCSH-OLEDs achieved experimentally: (i) 1.57 fold higher front-surface external quantum efficiency and light extraction efficiency (29% and 32% without lens, 55% and 60% with lens) – among the highest reported (Fig. 2a); (ii) ambient light absorption not only 2.5 fold higher (92% max, 74% average), but also broad-band (400 nm) and nearly angle and polarization independent, leading to lower glare (Fig. 1b); (iii) a contrast of 5 fold higher (12,000, 1,600, and 160 for 140, 1,000 and 10,000 lux ambient light) and the highest efficiency-absorption-product over previous LEDs (Fig. 2b); (iv) a viewing angle tunable by the cavity length – either narrower or wider than Lambertian (38^o tunability demonstrated); (v) 1.86 fold higher normal-view brightness ($65{,}000 cd/m^2$ luminance at $75 mA/cm^2$); (vi) 4.2 ohm/sq sheet-resistance --2.5 fold lower; and (vii) uniform color over all emission angles.

Furthermore, PlaCSH-OLEDs, a simple structure to fabricate, were fabricated using nanoimprint over large area (up to 1,000 cm^2), hence scalable to wallpaper size. PlaCSH-OLED's performances can be further improved with optimized structures and materials. The work opens up many new opportunities in high-performance LEDs and displays.

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[2] Y. Sun and S. R. Forrest, Nat. Photonics 2, 483-487 (2008)
[3] K. Ziemelis, Nature. 399, 408 (1999).
[4] S. Y. Chou, and W. Ding, Opt. Express. A60, Vol. 21, No. 21 (2013).

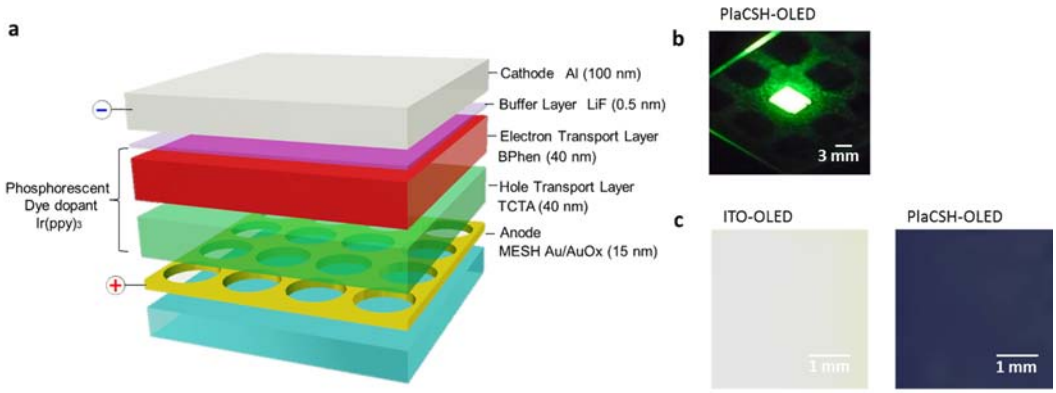

Figure 1: Organic Light Emitting Diode (OLED) of Plasmonic Cavity with Subwavelength Hole-array (PlaCSH): (a) Structure schematic: a top (Au) metallic-mesh electrode with subwavelength hole-array (MESH), a back electrode (LiF/Al), and in between thin layers of green phosphorescent organic host–guest materials: BPhen and TCTA (both Ir(ppy)3 doped); photographs of (b) green light emission from PlaCSH-OLED and (c) ambient light reflection of reference ITO-OLED (white) and PlaCSH-OLED (dark blue).

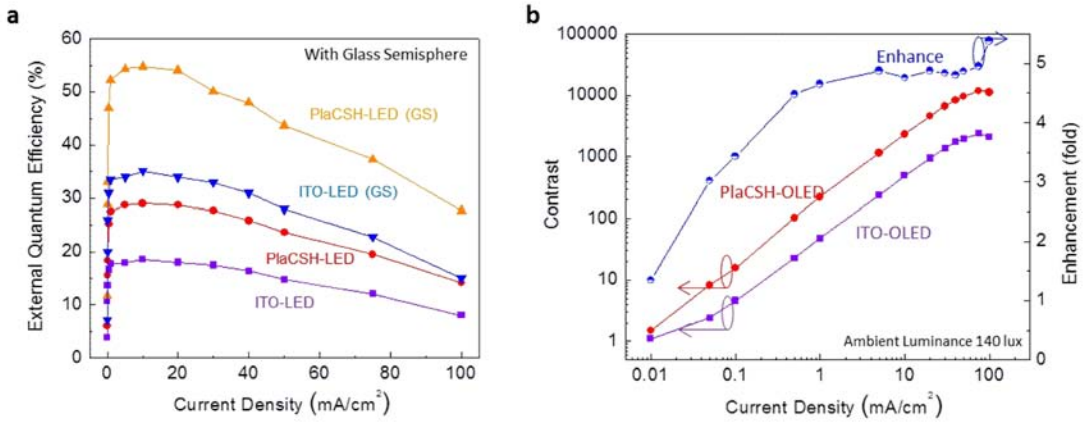

Figure 2: EQE and Contrast of PlaCSH-LEDs and ITO-LEDs: (a) EQE of ITO-OLED and PlaCSH-OLED without/with the glass half-sphere (GS) out-coupling. Compared to ITO-LEDs, PlaCSH-OLED has an EQE (at 10mA/cm^2) of 29.1% and 54.5% for without and with the glass half-sphere, both are 1.57 fold higher than ITO-OLED (18.5% and 35%). (b) Contrast of ITO-OLED and PlaCSH-OLED versus current density at 140 lux ambient luminance. Experiments show that PlaCSH-OLED's contrast achieves 12,000 at 75mA/cm^2, and is about 4-5 times higher than ITO-OLED.