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The Suppression of Viewing Angle Dependence of Top Emission Organic Light Emitting Diodes Having Strong Microcavity Characteristics by Applying Concave Patterned Anode

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Abstract

In order to obtain the stable viewing angle characteristics of top emission organic light emitting diodes (TEOLEDs) having strong microcavity characteristics, we fabricated nano-porous film on the glass substrate before depositing highly reflective anode. And then, we could obtain the concave patterned anode by depositing anode on the nano-porous film and fabricated TEOLED composed of concave patterned layers. From this approach, we could successfully obtain not only the stable color shift and luminance distribution with viewing angle but also high efficiency caused by uneven morphology. In addition, we found that the driving voltage of TEOLED could be reduced due to increased surface area effect of the concave patterned anode, so that the power efficiency was enhanced by about 15% in comparison with reference device.

Author Keywords

Concave electrode; TEOLED; nano-porous film; outcoupling enhancement; viewing angle dependence

1. Introduction

The organic light emitting diodes (OLEDs) are rapidly applied in mobile display applications because of their high contrast ratio, vivid color, rapid response time, slim and flexible design form factor, etc. In particular, since mobile products are requiring low power consumption to realize long battery life time, the efficiency of OLED is very significant study theme. Thus, many research groups and display panel manufactures have studied the outcoupling enhancement of OLEDs for last decades to obtain highly power efficient devices because the maximum outcoupling efficiency of typical OLEDs without using such technologies is not more than 20% although internal quantum efficiency of OLEDs themselves is almost 100% because the light loss is inevitably occurred by the total internal reflection (TIR) and/or surface plasmon coupling, absorption, etc. As a result, lots of technologies such as scattering glass, micro lens array (MLA), corrugated substrate, etc. were tried to reduce such kinds of loss mechanisms.[1-4] Nevertheless, those technologies couldn't be applied to the display applications due to a pixel blurring effect.[5,6]

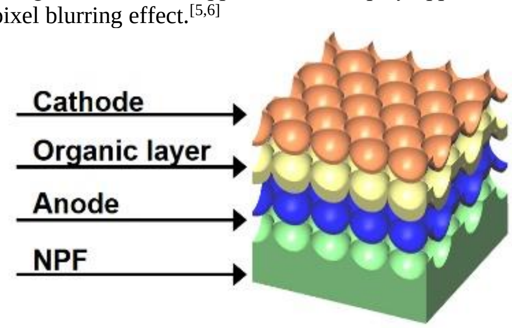

Figure 1. Schematic diagram of TEOLED having concave patterned anode.

To overcome this side effect, we enhanced the light power by microcavity structure although such device show very narrow angular emission pattern and large angular color shift. However, we could obtain stable viewing angle characteristics from such strong microcavity devices when we applied concave patterned anode by depositing on the nano-porous film. As shown in **Figure 1**, each layers including electrodes are transferred as pattern of nano-porous film by thermal evaporation and their topologies are all concave pattered. Through transferring this concave pattern, we could reduce the waveguide loss and suppress viewing angle dependence of TEOLED caused by the Fabry-Perot resonance characteristics.

2. Experimental

Preparation of nano-porous film

The nano-porous film was prepared by spin coating process with supplying water mist as shown in **Figure 2(a)**.[7,8] We used poly(methyl methacrylate) (PMMA) as film material and dissolved it in the therahydrofuran (THF) solution. After finishing spin coating process, we dried this film over 10 minutes at room temperature; about 20°C. The pores in film were randomly distributed in PMMA base film with a diameter of about 500 to 1000 nm as shown in **Figure 2(b)**. Meanwhile, thickness of film and depth of pore were about 2μm and 500 nm, respectively, as shown in **Figure 2(c)**.

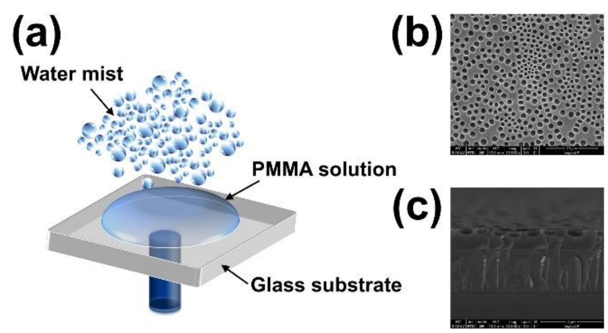

Figure 2. Schematic diagram of preparation of nano-porous film; (b) SEM image of the front view of nano-porous film; (c) SEM image of the cross section of nano-porous film.

Fabrication of TEOLED

The glass substrates were used with 0.5 mm thickness and cleaned in acetone and isopropyl alcohol with a sonication process to remove residual impurities. We used multilayered aluminum (Al) / silver (Ag) as an reflective anode; magnesium (Mg) and Ag as semitransparent cathode; lithium quinolate (Liq) as an electron injection layer; GH and GD as a phosphorescent green host and dopant materials for emitting layer (EML); HTL1

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as a hole transporting layer (HTL) and capping layer (CL), HTL2 as a HTL and/or exciton blocking layer (EBL) to suppress exciton quenching in the devices; CGL as a charge generation layer; ETL as electron transport layer. All materials were purchased from commercial suppliers and deposited by thermal evaporation. **Figure 3** shows the detail device structures to evaluate efficiency and viewing angle characteristics.

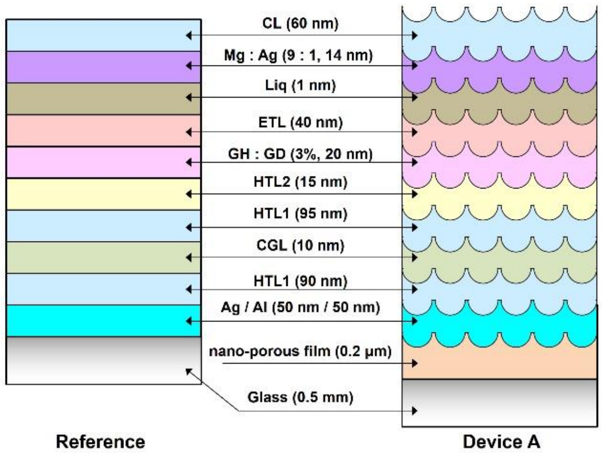

Figure 3. Schematic device structure comparison.

Reference : Glass (0.5mm) / Al (50nm) / Ag (50nm) / HTL1 (90nm) / CGL (10nm) / HTL1 (95nm) / HTL2 (15nm) / GH:GD (3%, 20nm) / ETL (40nm) / Liq (1.5 nm) / Mg:Ag (9:1, 14nm) / HIL1 (60nm)

Device A : Glass (0.5mm) / nano-porous film (2μm) / Al (50nm) / Ag (50nm) / HTL1 (90nm) / CGL (10nm) / HTL1 (95nm) / HTL2 (15nm) / GH:GD (3%, 20nm) / ETL (40nm) / Liq (1.5 nm) / Mg:Ag (9:1, 14nm) / HIL1 (60nm)

Measurements

The characteristics of current density–voltage (J–V) and luminance–voltage (L–V) were measured by Keithley 238 and Minolta CS-2000A. The power efficiency and EQE were calculated by integrating angular luminance of goniometer with CS-2000A. The morphology of nano-porous film was evaluated by field emission scanning electron microscopy (FE-SEM, S-4700, Park Systems).

3. Results and Discussion

Investigation of efficiencies of devices

We fabricated TEOLEDs having strong microcavity by using semitransparent cathode, Mg:Ag co-deposition. To clearly investigate viewing angle dependence characteristics, we increased total HTL thickness by 10nm from the 2nd ordered microcavity thickness. **Figure 4(a)** shows J-V-L characteristics of devices. The current density of Device A is higher than reference in the same operating voltage because the contacting surface area between anode and HTL increased due to concave anode morphology. As our expectation, the reference device had the maximum luminance at not normal direction but viewing angle, 25°, due to additional thickness increasement by 10nm from the 2nd ordered microcavity thickness as shown in **Figure 4(b)**. Very interestingly, the angular luminance distribution of Device A was very similar to the lambertian distribution and luminance value of Device A was higher than reference device at the normal direction. Due to this angular luminance distribution result, the current and power efficiencies at 1000 cd/m^2 were 97 cd/A and 67 lm/W for reference device, 112 cd/A and 77 lm/W for Device A, respectively, as shown in **Figure 4(c)**.

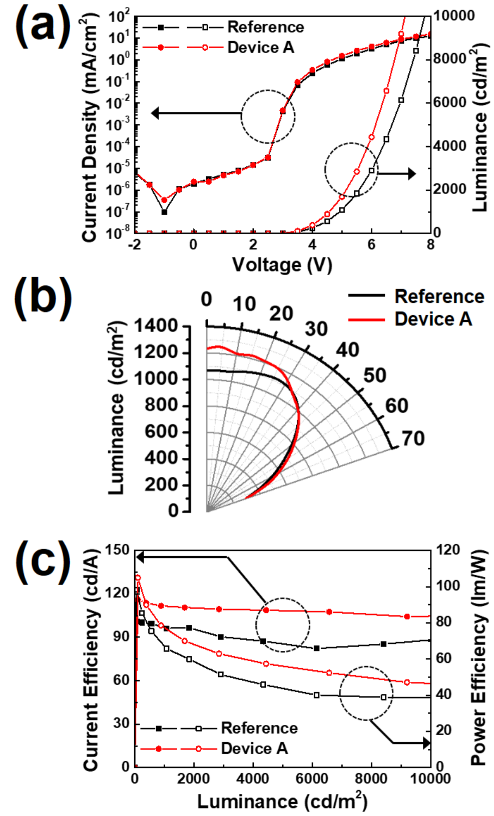

Figure 4. (a) J-V-L characteristics of devices; (b) angular luminance distribution characteristics of devices; (c) luminance-current efficiency and power efficiency characteristics of devices.

The optical characteristics of devices were summarized in **Table 1**.

Table 1. The optical characteristics summary of devices.

Item	Reference	Device A
Operating Voltage[a]	4.9 V	4.6 V
Current Efficiency[a,b]	97 cd/A (101 cd/A)	112 cd/A (116 cd/A)
Power Efficiency[a,b]	67 lm/W (98 lm/W)	77 lm/W (105 lm/W)
EQE[a,b]	26 % (27 %)	28 % (29 %)
(x, y)[a,c]	(0.322, 0.658)	(0.273, 0.691)

[a] Measured at 1000 cd/m^2, [b] The parenthesis denotes the maximum efficiency, [c] Color coordinates by CIE 1931 color system.

Investigation of angular color shifts of devices

We investigated the angular color shift characteristics of TEOLEDs by applying concave anode. The color shift was calculated as following formula.

$$\Delta u'v' = \sqrt{(u'_x - u'_0)^2 + (v'_x - v'_0)^2}$$

where u'_x and v'_x mean *u'* and *v'* values at the viewing angle of *x* degree and u'_0 and v'_0 mean *u'* and *v'* values at the viewing angle of 0 degree in CIE 1976 color system. The color shift of device means the maximum value of *Δu'v'* from 0° to 60°. Very interestingly, the color shifts of reference and Device A were 0.072 and 0.024, respectively, as shown in **Figure 5(a)**. it means that concave patterned anode can improve poor angular color shift by about 3 times from reference device. Meanwhile, the EL peak wavelength shifts of reference and Device A were 35 nm and 21 nm, respectively, as shown in **Figure 5(b)** and **5(c)**.

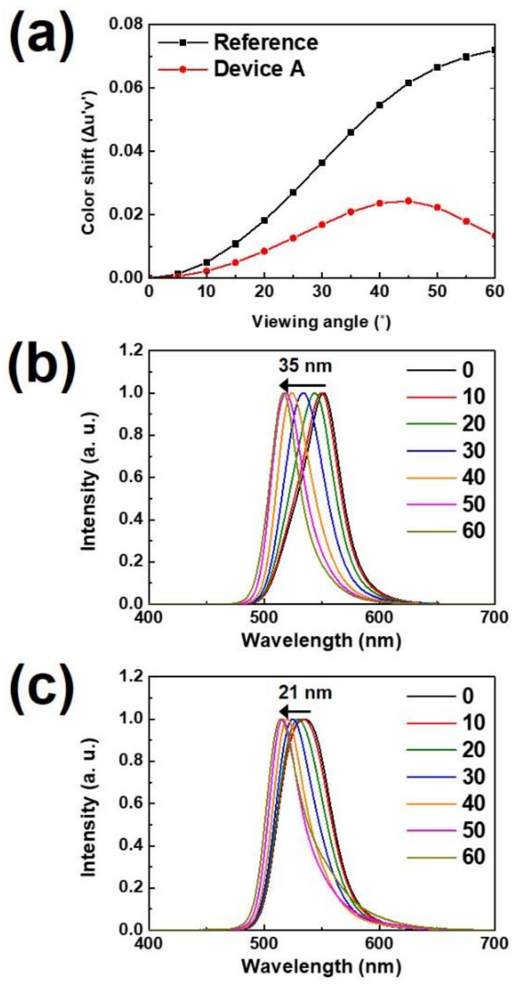

Figure 5. (a) Angular color shift (Δu'v' in CIE 1976 color system); (b) angular EL spectrum shift of reference; (c) angular EL spectrum shift of Device A.

4. Conclusions

We improved not only the current and power efficiencies but also poor angular characteristics of TEOLED having strong microcavity characteristics, such as narrow angular luminance distribution and big color shift by suppressing the Fabry-Perot resonance through applying uneven concave anode. From this approach, we enhanced the current and power efficiencies by about 15% and suppressed angular color shift by about 3 times from reference device without serious loss of color gamut. Moreover, since randomly distributed nano sized concave patterns don't cause moiré phenomenon caused by interference effect of regular pattern arrangement, it can be good solution for suppressing viewing angle dependence in the display application.

5. Acknowledgement

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