Displays 44 (2016) 37–41

Contents lists available at ScienceDirect

Displays

journal homepage: www.elsevier.com/locate/displa

Fabrication and characterization of double-sided organic light-emitting diodes using silver and nickel as the metal linking layer

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ARTICLE INFO

Article history:
Received 18 October 2014
Received in revised form 30 June 2016
Accepted 2 July 2016
Available online 5 July 2016

Keywords:
Double-sided emitting
Organic light-emitting diode
Metal linking layer
Modulation

ABSTRACT

In this work, a novel double-sided emitting organic light-emitting diode (DE-OLED) was developed, and the effect of several metal linking layers on such DE-OLEDs was investigated. To form a DE-OLED, a metal linking layer was thermally deposited between a bottom-emitting organic light-emitting diode (BE-OLED) and a top-emitting organic light-emitting diode (TE-OLED). A series of metal films of 10-nm Ag, 20-nm Ag, 10-nm Ag/10-nm Ni, and 20-nm Ni were used as the linking layers, and 20-nm Ag based DE-OLEDs show the highest current efficiency and luminance. Two types of DE-OLEDs, including monochromatic and dichromatic, have been fabricated successfully. The EL spectrum of the TE-OLED is significantly narrower than that of BE-OLED because of the microcavity effect in both monochromatic and dichromatic DE-OLEDs. The results indicate that the electroluminescent characteristics of the OLED devices at both (bottom and top) sides can be modulated independently by using the metal linking layer without sacrificing the brightness and color stability of the device.

1. Introduction

Since the first planar-heterojunction organic light-emitting diode (OLED) was reported by C.W. Tang in 1987, OLEDs have attracted considerable attention in the application of flat panel display and lighting because of its light weight, high brightness, fast response time, low operation voltage, wide color gamut, wide viewing angle, wide operating temperature range, and low power consumption [1–4]. Novel applications of OLEDs as architectural windows, aesthetic light source, and see-through (transparent) display have also been expected [5,6].

To date, the research on see-through OLED displays have focused on the species of transparent cathodes, such as, metal oxides or metals in top emitting OLEDs (TE-OLEDs), and the thickness of cathodes [7–9]. When the thickness of metal films, such as, Ag, Ca/Ag, Mg/Ag, and Au, is lower than 45 nm, a transmittance effect can be obtained [10–12]. The radiation distribution of transparent OLEDs was also found to depend significantly on the species and thickness of the metal [13]. However, the luminance intensities of double-sided emitting OLEDs (DE-OLEDs) cannot be modulated independently by only modifying the cathode, which limits its application on see-through display or lighting [14,15]. Recently, some progress for resolving this problem has been reported. Ko et al. reported a 1.5-in. full color double-sided active matrix OLED, in which independent images at each side can be displayed [16]. Sun et al. reported an efficient DE-OLED which can be used in a passive matrix driving scheme with independent control of double-sided display [17,18]. However, there are limited reports on the metal linking layers in DE-OLEDs, despite the important role played by such bipolar electrodes in DE-OLEDs [17,19].

In this work, we propose to use a metal linking layer in a DE-OLED which is capable of emission at both sides. By varying the species and thicknesses of metals, namely, Ag or Ni, the monochromatic DE-OLEDs with four different metal linking layers were fabricated and the electro-optical performances were investigated in detail. In addition, an efficient dichromatic DE-OLED containing two different emissive dopants based on the optimized metal linking layer has also been demonstrated.

2. Experimental

As shown in Fig. 1, a series of monochromatic OLEDs (Devices A-1, A-2, A-3, and A-4) with different metal linking layers and same emissive layer in two sub-units were fabricated to study the electro-optical characteristics. The overall device architecture is ITO/bottom-emitting organic light-emitting diode (BE-OLED)/linking layer/TE-OLED/cathode. For detailed Devices A 1–4, the structures are MoO_x (2 nm)/N,N′-bis(naphthalen-1-yl)-N,N′-bis

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http://dx.doi.org/10.1016/j.displa.2016.07.001
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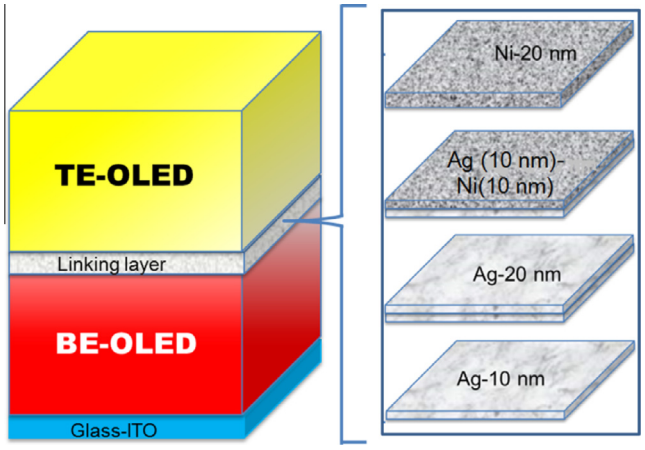

Fig. 1. Schematic diagram of DE-OLED device structure with various linking layers.

(phenyl)benzidine (NPB) (55 nm)/tris(8-hydroxyquinoline) aluminum (Alq_3) (50 nm)/8-hydroxyquinolatolithium (Liq) (1 nm)/Al (100 nm) and MoO_x (2 nm)/NPB (55 nm)/Alq_3 (50 nm)/Liq (1 nm)/Al (10 nm) for BE-OLED and TE-OLED, respectively. Four-types of linking layers were used to connect BE-OLED and TE-OLED for comparison, including 10-nm Ag (Device A-1), 20-nm Ag (Device A-2), 10-nm Ag/10-nm Ni (Device A-3), and 20-nm Ni (Device A-4).

In addition, we also fabricated a dichromatic device (Device B) using the structure similar to the monochromatic DE-OLED just with two different emissive dopants. The detailed device architecture is MoO_x (2 nm)/NPB (50 nm)/Alq_3:propanedinitrile, [2-(1,1-dimethylethyl)-6-[2-(2,3,6,7-tetrahydro-1,1,7,7-tetramethyl-1H,5H-benzo[ij]quinolizin-9-yl)ethenyl]-4H-pyran-4-ylidene] (DCJTB) (20 nm)/Alq_3 (55 nm)/Liq (1 nm)/Al (100 nm) and MoO_x (2 nm)/NPB (50 nm)/Alq_3:5,6,11,12-tetraphenyl-naphthacene (rubrene) (30 nm)/Alq_3 (55 nm)/Liq (1 nm)/Al (10 nm) for BE-OLED and TE-OLED, respectively. 20-nm Ag functions as the linking layer in Device B. By considering the microcavity effect, we used another 30-nm Alq_3 as the capping layer for TE-OLED in all the Devices A and Device B. Introduction of the capping layer not only suppresses effectively the blue-shift of transverse magnetic (TM)-polarized light, but also maintains the shift of the transverse-electric (TE)-polarized light [20].

In these devices, MoO_x served as the hole-injection layer, Liq was used as the electron-injection layer, and Alq_3 as well as NPB

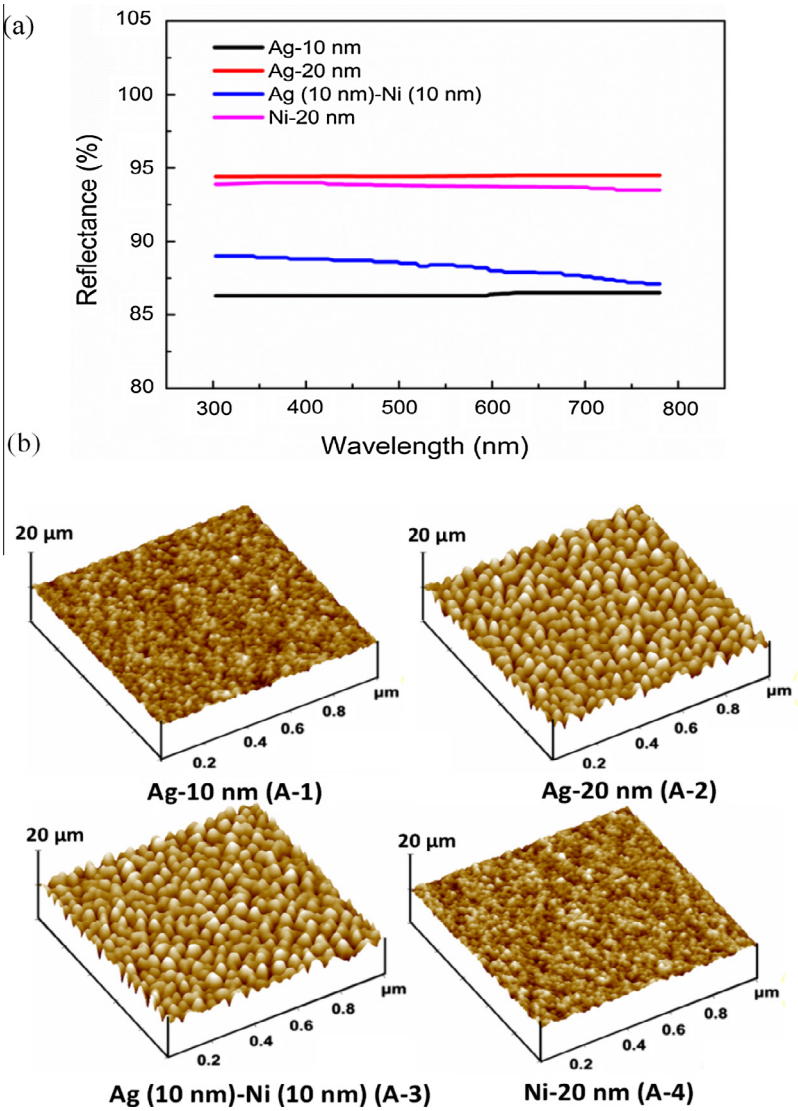

Fig. 2. (a) Reflectance of linking layers for 10-nm Ag, 20-nm Ag, 10-nm Ag/10-nm Ni, and 20-nm Ni, respectively. (b) AFM images of the corresponding linking layers.