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Implementation of anti-reflection coating to enhance light out-coupling in organic light-emitting devices

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Abstract

We report significant enhancement of light out-coupling in organic light-emitting devices (OLEDs) by means of anti-reflection coating of magnesium fluoride (MgF_2) on the backside of glass substrate. OLEDs were fabricated by employing the green electrophosphorescent material *fac* tris-(2-phenylpyridine) iridium [$Ir(ppy)_3$] doped in 4,4′,8-*N*,*N*-8-dicarbazole-biphenyl (CBP) and 0.4 wt% tetrafluorotetracyano-quinodimethane (F4-TCNQ)-doped naphthylphenylbiphenyl diamine (α-NPD) as hole transport layer (HTL). Single-layer MgF_2 with the thickness of $\lambda/4$ was then vacuum deposited on the backside of glass substrate of OLED. About two-fold enhancement in luminance with anti-reflection coating of MgF_2 has been observed.

Keywords: Organic light-emitting devices; Light out-coupling; Anti-reflection coating technique.

1. Introduction

There has been considerable amount of research and development for the improvement of efficiency of organic light-emitting devices (OLEDs) because of their potential applications in general illumination, flat panel displays, automotive and outdoor lighting. Numerous efforts have been made to improve their external coupling efficiency ($\eta_{cp,ext}$) by means of improved device concepts, such as electrode modifications, synthesis of new organic materials and modification in device structure [1–7]. It is well understood that the generated light from the active OLED medium propagates via various modes, that is, external modes (escape from the substrate surface), substrate-, and ITO/organic-waveguided modes due to total internal reflection (TIR) [6–8]. According to the ray optics theory, about 80% of the generated light is lost in waveguided modes due to glass substrate and ITO/organic material which means that the majority of generated light is either trapped inside the glass substrate and device, or emitted out from the edges of an OLED [6–8]. For the purpose of applications in general illumination and flat panel displays, light emitted from the substrate surface (external modes) is most useful which is only about 20% of the total emitted light from the OLED. To extract the trapped and waveguided light into external modes, various approaches based on light refraction and scattering to reduce TIR at the interfaces have been reported, such as, the use of a shaped substrate [6,7], use of micro-lenses on the backside of substrate surface [8–10], formation of mono-layer of silica micro-spheres as scattering medium [11,12], and use of high refractive index substrate [13]. In another approach, an extremely low refractive index silica-aerogel layer [14] was inserted between the ITO transparent electrode and glass substrate. A 50% light extraction efficiency from OLEDs was recently reported by insertion of a two-dimensional photonic crystal structure [15–18], and using nano-porous and nano-patterned films [19–21]. More recently, use of diffusive layer lamination [22],

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holographic technique [23], and shaped substrate OLED luminair [24] has also been investigated for the improvement of out-coupling efficiency in conventional OLEDs. An index-matching layer has also been used for top-emitting OLED [25].

In this letter, we report significant enhancement of external out-coupling efficiency of conventional OLEDs by means of simple anti-reflection (AR) technique using single-layer coating of magnesium fluoride (MgF_2) on the backside of glass substrate [26]. Magnesium fluoride was chosen because it is the most widely used single-layer AR (SLAR) coating material for optical components to avoid reflection from air-glass boundary and enhance transmission [27]. MgF_2 has been ideal choice for single or multi-layer AR-coating on all optical components because of its low refractive index ($n_{MgF_2} = 1.38$ at 550 nm), high transmissivity, high durability and nearly ideal for the task of providing minimum reflectance with only a single-layer film [27]. It exhibits broadband characteristics and can be applied on a variety of substrates for use in spectral regions from UV to NIR. Furthermore, MgF_2 is a birefrigent crystal material with excellent physical and chemical properties, that is, it is a rugged material resistant to chemical etching, mechanical, and thermal shock. Furthermore, MgF_2 can be easily coated on all kind of substrates by thermal evaporation and extracted illumination pattern remains uniform, symmetric and planar Lambertian [24,28] and is most useful for general purpose lighting and flat panel displays.

2. Device fabrication and results

OLEDs were fabricated by vacuum evaporation technique on cleaned indium tin oxide (ITO)-coated glass substrates first treated by O_3 plasma. The thickness and refractive index of glass (n_{glass}) were 1.0 mm and 1.55, respectively. Device configuration consisted of 350-Å-thick α-naphthylphenylbiphenyl diamine (α-NPD) ($n_{NPD} = 1.76$) doped with 0.4 wt% tetrafluorotetracyano-quinodimethane (F4-TCNQ) as hole transport layer (HTL), 250-Å-thick 4,4′,8-*N*,*N*′-8-dicarbazole-biphenyl (CBP) doped with 6 wt% of green electrophosphorescent material, *fac* tris-(2-phenylpyridine) iridium [$Ir(ppy)_3$] as emissive layer, 60 Å 2,9-dimethyl-4,7-diphenyl-1,10-phenanthroline (bathocuproine or BCP) as hole blocking layer, and 300-Å-thick tris-(8-hydroxyquinoline) aluminum (Alq_3) ($n_{Alq} = 1.71$) as electron transport layer. The cathode of the device consisted of 10-Å-thick LiF layer and a 1000-Å-thick aluminum layer. The device was then encapsulated using glass cover slips. The electroluminescence (EL) spectrum of the OLED device was recorded by coupling the output through a fiber-optic cable to a high-resolution spectrometer (Model no. HR-4000, Ocean Optics Inc.) interfaced to an IBM PC. The output luminance of both the devices was measured using luminance meter L1000 (LMT, Germany). Backside of the glass substrate of both OLED devices was then coated with MgF_2 of thickness $\lambda/4$. The MgF_2 was deposited by thermal evaporation technique without substrate heating. In order to avoid the mild heating effect during MgF_2 deposition, we first coated the MgF_2 on one half the part of the backside of the glass substrate containing two segments of ITO. Another half of the glass substrate was left uncoated with MgF_2. Then, the OLEDs were fabricated and the measurements were carried out. Fig. 1 shows the output light intensity versus voltage of the device. Dotted and solid curves show the output light intensity with and without MgF_2 coating on the backside of glass substrate, respectively. A significant enhancement in light intensity was obtained with AR-coated glass substrate. Inset in Fig. 1 shows the current density (J) versus luminance (L) of the OLED device. Ratio of

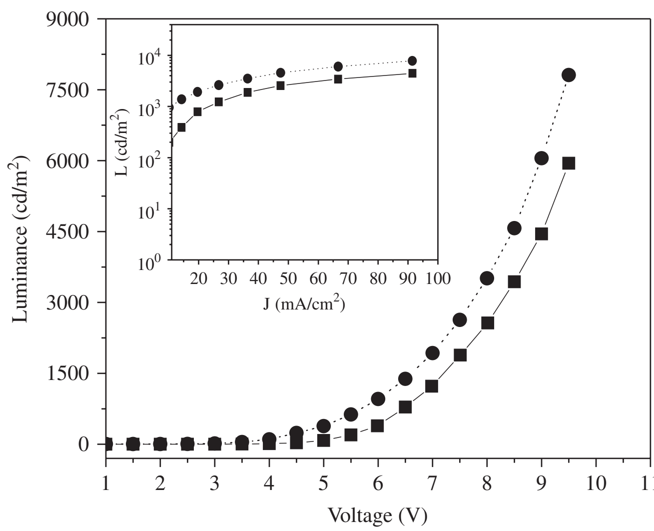

Fig. 1. Output light intensity (L) versus voltage (V) from OLED device. Dotted and solid curves are the output light intensity with and without MgF_2 coating on the backside of glass substrate, respectively. Inset shows the current density (J) versus luminance (L) of the device before (solid line) and after (dotted line) coating MgF_2 on the backside of glass substrate.

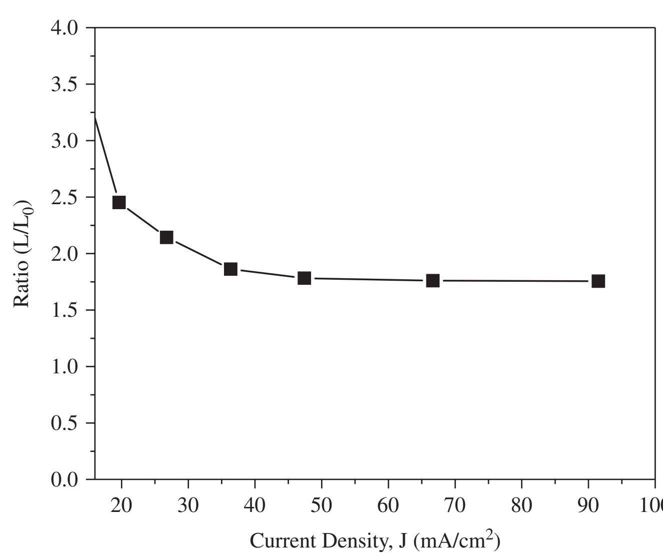

Fig. 2. Ratio of luminance (L/L_0) versus current density (J).