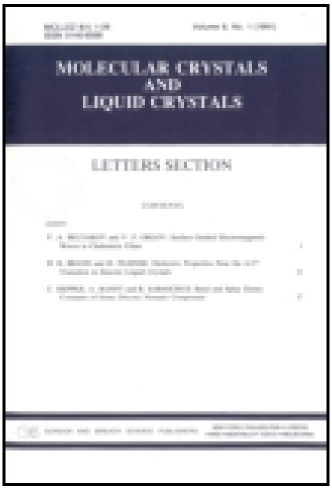

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Solution Process of Encapsulation Layer for Organic Light Emitting Diode for Enhanced Performance

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Solution Process of Encapsulation Layer for Organic Light Emitting Diode for Enhanced Performance

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This research presents fabrication process of an encapsulation layer for organic light-emitting diodes(OLED) and its optical performance. We have developed a novel encapsulation layer for organic light-emitting diodes(OLEDs) using poly(dimethysiloxane) (PDMS) including scattering particles. This encapsulation layer can be fabricated by the solution process. The OLED with the proposed encapsulation layer has an excellent optical performance. The external quantum efficiency(EQE) has been improved by 42%. We expect the proposed encapsulation layer will be used where EQE is a key factor.

Keywords Organic light-emitting diode; encapsulation layer; solution process; external quantum efficieny; poly(dimethysiloxane)

Introduction

Recently, there have been many researches regarding the next-generation display [1]. Requirements for next-generation display should be thinner, more vivid, wide viewing angle, and flexible characteristics. One promising approach to the next-generation display is the Organic light emitting diodes (OLEDs), which have rapidly developed over the last decade, because of their potential application areas [2].

OLED was first proposed with thick organic crystals sandwiched between electrodes in the 1960s. [3, 4] However, it is limited in practical use due to the high operating voltage. In 1987, Tang and VanSlyke reported the first practical OLEDs [5]. Since then, OLEDs have been subjects of intensive studies due to their various advantages for the solid-state lighting, display backlight, and display applications.

Light efficiency is one of important parameters for OLED device performance. The optical efficiency of the OLED is mainly expressed in the external quantum efficiency (EQE). The EQE of the OLED device is related to the internal quantum efficiency and the

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external coupling efficiency. The EQE of the OLEDs can be express as; [6, 7].

$$\eta_{ext} = \eta_{int}\eta_{coupling} = \gamma\eta_{exc}\phi_p\eta_{coupling} \tag{1}$$

where γ is the electron-hole charge balance factor, η_{exc} is the fraction of total number of excitons formed which result in radiative decay, and φ_{p} is the intrinsic quantum efficiency for radiative decay. However, although internal quantum efficiency is nearly achieved as 100%, the external coupling efficiency of the conventional OLED device remains very low. [7] With the isotropic emission in the organic layer and a perfectly reflecting cathode, external coupling efficiency can be represented as: [2, 6–8].

$$\eta_{ext} = \frac{1}{\xi n^2} \tag{2}$$

Where n is the refractive index of OLED material and ξ is a constant that depends on the dipole alignment and the geometry of the OLED device. Most of the organic materials have the value of 2 for ξ. Generally, the internal coupling efficiency is only about 20%. According to classical ray optics theory(Snell's raw) about 80% of generated light is lost in wave-guided modes due to glass substrate and ITO/organic material which means that the majority of the light is either trapped inside the glass substrate and device, or emitted out from the edges of an OLED [2, 8–10].

On the other hand, to achieve a long lifetime, the encapsulation layer with glass or organic/inorganic multilayer is required. The OLEDs require the barrier layer which transmits less than 10^{-5} gm^{-2}d^{-1} of water and 10^{-3} cm^{3}m^{-2}d^{-1} of oxygen. [11, 12] The OLED device with the glass encapsulation layer is not flexible. For the flexible display application with a simple fabrication process, Poly(dimethyl-siloxane) (PDMS) was used for the encapsulation layer of the OLED. PDMS has the flexibility and chemical resistance. Recently, the water and oxygen permeation rate of the PDMS encapsulation layer was reduced to 10^{-7} gm^{-2}d^{-1} [13]. In this paper, we demonstrates the enhanced light external coupling efficiency with an PDMS encapsulation layer including silica ball by the scattering effects.

Experimental Procedure

The indium-tin-oxide (ITO) coated glass was used as the substrate. Before coating the organic materials, ITO glass was cleaned by acetone, Isopropyl alcohol (IPA), gradually. The hole injection layer (HIL) was formed on ITO glass by spin coating of solution of poly(3,4-ethplenedioxythiophene) poly(styrenesulfonate) (PEDOT:PSS). The emission layer was formed on PEDOT:PSS coated ITO glass by spin coating of solution of 4,4′-N,N′-dicarbazole-biphenyl (CBP) and argentum (Ag) is used as the cathod electrode. Finally, the structure of the fabricated OLED was encapsulated by the PDMS layer including silica ball. Figure 1 shows the faricated structure of the OLED with PDMS encapsulation layer including scattering particles.

The fabrication process of the PDMS encapsulation layer including scattering particles is as follows. First, the PDMS pre-polymer (Saylgard 184, Dow corning) was poured onto a dish. After that, by mixing the silica balls, the scattering particles are suspended into PDMS pre-polymer. After driving out the air bubbles in a vacuum oven, with a curing agent, the PDMS was cured for 20 min at a temperature of 100°C.

To investigate the particle size effects on the light scattering, we fabricated 200 um thickness of the PDMS layers with various sizes of the particles. The diameters of the particles were 2.25 um, 5 um, 10.5 um, 20.7 um, and 52.5 um. The particles are mixed into the PDMS layer with 5 wt%, respectively. Figure 2 shows the fabricated PDMS layers

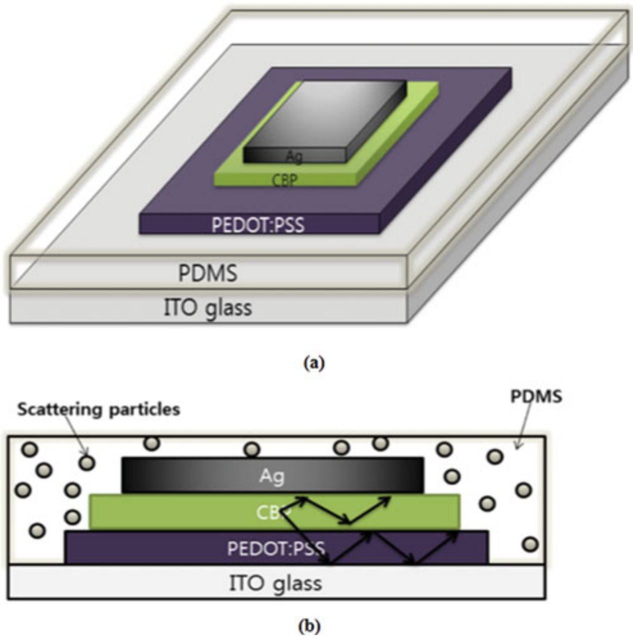

Figure 1. The structure of the fabricated OLED with PDMS encapsulation layer, including scattering particles : (a) The schematic structure of fabriacated OLED with PDMS encapsulation layer including scattering particles, (b) the cross-sectional view.

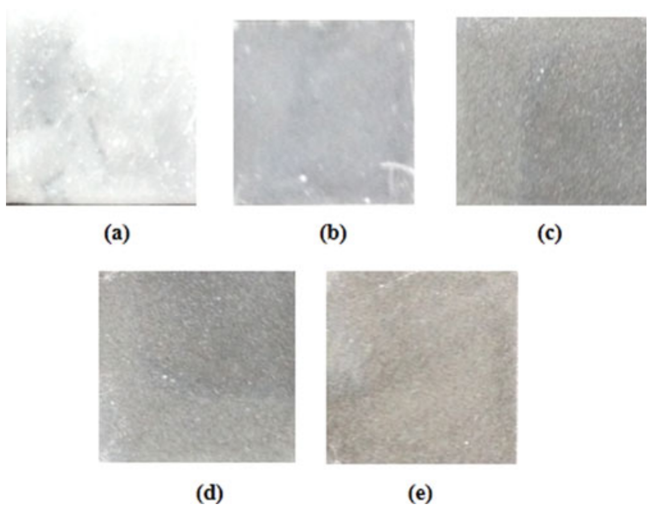

Figure 2. Fabricated PDMS layers with the particle diameters of (a) 2.25 um, (b) 5 um, (c) 10.5 um, (d) 20.7 um, and (e) 52.5 um.

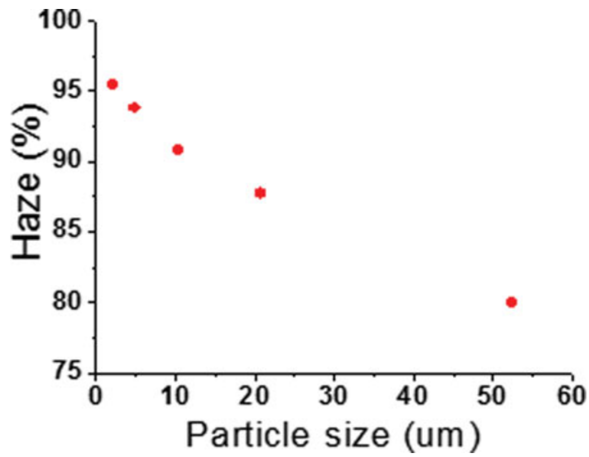

Figure 3. The measured haze values with respect to the particle sizes.

with various particle sizes on the black background. To verify the scattering effects of the fabricated layer. We measure the haze of the fabricated layers with a green laser, whose wavelength is 532 nm. The haze is represented as

$$\text{Haze} = \frac{I_{\text{scattering}}}{I_{\text{incident}}} \times 100 \tag{3}$$

The measured haze values with respect to the various particle sizes are shown in Fig. 3. The smaller the particle size is, the higher the haze value is. The measured haze values were 95%, 93.8%, 90.8%, 87.7%, and 80% as shown in Fig. 3.

Experimental Results

The light efficiency of OLED was measured by the integrating sphere system (FOIS-1 fiber optics integrating sphere, ocean optics). Figure 4 shows the luminance of fabricated OLEDs with the glass encapsulation (a) and with PDMS encapsulation layer including scattering

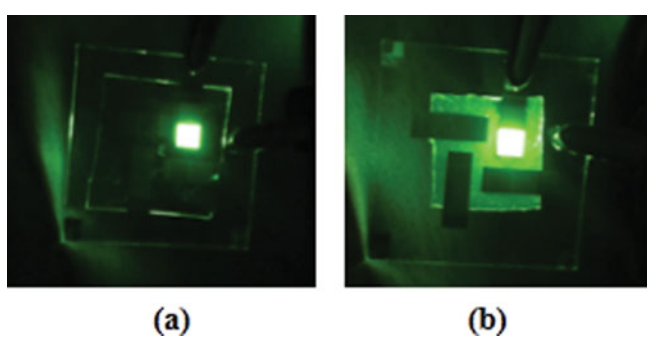

Figure 4. Luminance of the fabricated OLEDs with (a) the glass encapsulation and (b) with PDMS encapsulation layer including scattering particles.

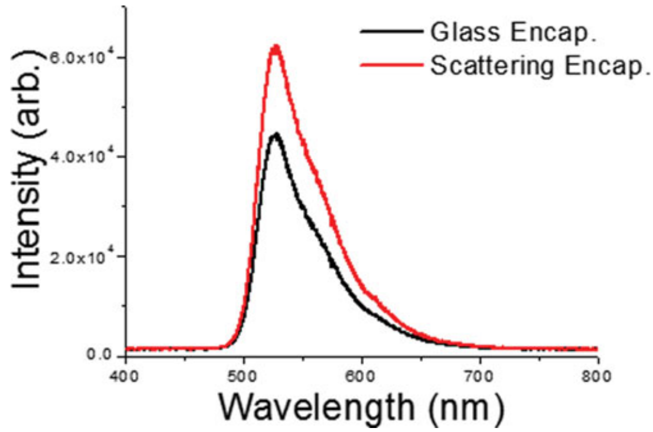

Figure 5. The optical characteristics of the fabricated OLED.

particles (b). The EQE of OLED is expressed by the following equation [14]

$$\eta_{ext} = \frac{\pi \mathrm{Le}}{\mathrm{K_m hcJ}} = \frac{\int^{\lambda F}(\lambda)\, d\lambda}{\int^{F}(\lambda)\, y(\lambda)\, d\lambda} \tag{4}$$

where L is the luminance (cd/m^2), K_m is the maximum spectral luminous efficacy (685 lm/W), and J is the current density (A/m^2). F(λ) and y(λ) repesent the electroluminescence and the relative luminous efficiency, respectively. Using Eq. (3), EQE of OLED can be calculated from the measured luminance, current density and EL spectrum of OLED [15, 16].

The optical characteristics of the OLED with PDMS encapsulation layer including the scattering particles are compared with that of the OLED with the glass encapsulation in Fig. 5. Although both the device structures were the same, by using the scattering particles in the encapsulation layer, the optical efficiency was increased to 42%.

Conclusions

In this study, we have developed a novel encapsulation layer for organic light-emitting diodes(OLEDs) using poly(dimethysiloxane) (PDMS) including scattering particles. This encapsulation layer can be fabricated by the solution process. The OLED with the proposed encapsulation layer has an excellent optical performance. The external quantum efficiency(EQE) has been improved by 42%. We expect the proposed encapsulation layer will be used where EQE is a key factor.

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