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Air void optical scattering structure for high-brightness organic light emitting diodes

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ABSTRACT

In order to increase the outcoupling efficiency of organic light emitting diodes (OLEDs), a hexagonal array of air void optical scattering structures was formed on a glass substrate. The air void structure was fabricated by first depositing a monolayer of polystyrene (PS) spheres having a diameter of 820 nm on the substrate. A layer of hydrogen silsesquioxane (HSQ) was then coated on the resulting monolayer and finally, annealing was carried out to burn out the PS spheres and to cure the HSQ layer. The air void optical scattering structure on the glass substrate interacted with the generated photons and suppressed the total internal reflection of light at the surface of the glass. As a result, the OLED fabricated on this glass exhibited a 10% increase in the optical output.

1. Introduction

Organic light emitting diodes (OLEDs) have been an attractive research topic in the field of solid-state lighting owing to their low power consumption, faster response, good color gamut, and cost-effective fabrication. Over the past few decades, a significant improvement has been observed in the internal quantum efficiency of OLEDs. The value has reached nearly 100% [1–4]. However, the external quantum efficiency of OLEDs is still limited to the 20–30% range because of total internal reflection (TIR) and surface plasmon polariton absorption of light at the metal electrode [5–9]. This means nearly 70–80% of the generated photons are absorbed in an OLED device. Therefore, studies focusing on improving the outcoupling efficiency of OLEDs have gained huge interest, and various methods have been proposed to improve the outcoupling efficiency [10–12]. For example, roughening the surface of a substrate and creating an ordered array of micro/nano patterns on the backside of the substrate has been reported to be an effective way of improving the outcoupling efficiency [13–19].

In this work, a hexagonal array of air void optical scattering structures was fabricated on a glass substrate by first depositing polystyrene (PS) spheres on the glass substrate. The PS spheres were then coated by a layer of hydrogen silsesquioxane (HSQ). Finally, annealing was carried out to burn out the PS spheres and to cure the HSQ layer. Two HSQ solutions with different concentrations were used to control the thickness of the HSQ layer. The OLED layers were deposited on the opposite side of the air void optical scattering-structured substrate. The OLEDs with the air void optical scattering structure exhibited 10% higher electroluminescence (EL) than those without the air void structure.

2. Material and methods

2.1. Substrate fabrication

Fig. 1 shows the schematic of the fabrication process for the air void optical scattering structure on a glass substrate. In this experiment, Corning EAGLE XG glass was used as the substrate. The glass substrate was cleaned with sulfuric acid for 1 h in order to remove any metallic and organic contaminant and was then treated sequentially in ultrasonic baths of acetone, ethanol, and deionized water for 10 min. The glass substrate was then dried by nitrogen blowing and was placed in an ultraviolet-ozone (UV-O_3) chamber to make its surface hydrophilic. After the UV-O_3 treatment, a monolayer of PS spheres with a diameter of 820 nm (Thermo Scientific) was spin-coated at 1000 rpm for 1 min. A 10 wt% PS sphere solution dispersed in water was used. A uniform layer of PS spheres was obtained by controlling the spin-coating process carefully. The resulting PS monolayer was then coated with a layer of HSQ (Dow corning) by spin-coating [20]. The refractive index

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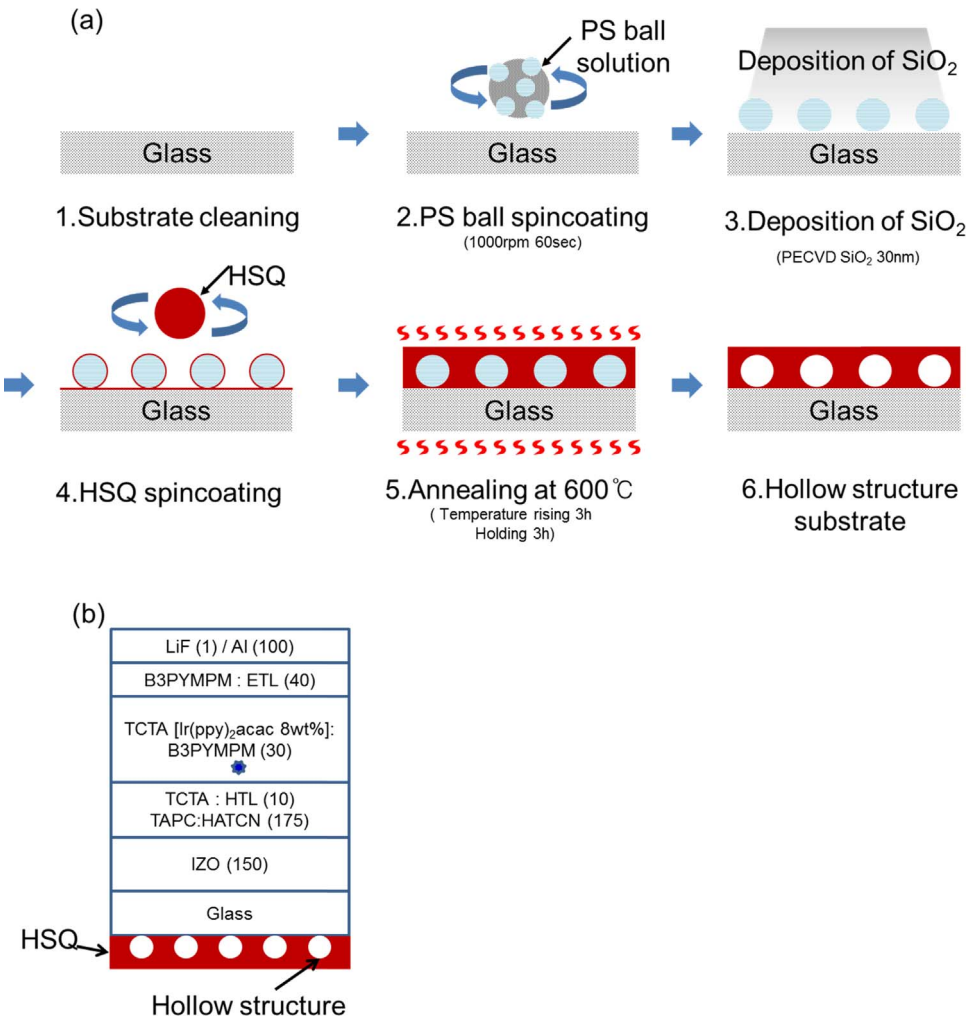

Fig. 1. (a) Schematic of the fabrication process for the air void optical scattering-structured substrate, (b) Schematic of the OLED device on the air void optical scattering-structured substrate.

of HSQ is comparable to that of glass. Since the solvent used for spin-coating HSQ is Methyl isobutyl ketone (MIBK) and PS spheres dissolve in MIBK, a 30 nm SiO_2 layer was deposited over the PS sphere layer as a protection layer by plasma enhanced chemical vapor deposition.

In order to investigate the effect of the HSQ layer thickness on the efficiency of the resulting OLEDs, 11 and 22 wt% HSQ solutions were used. After spin-coating, the HSQ layer was hardened by a UV-O_3 treatment. The glass was then annealed in a tube furnace at 600 °C for 3 h to burn out the PS spheres and to cure the HSQ layer. Once the air void scattering structure was formed, Indium Zinc Oxide (IZO) and organic layers were deposited on the opposite side of the air void scattering structured surface for fabricating the OLEDs.

2.2. OLED fabrication

The OLED fabrication process involved the following steps. First, an IZO (150 nm, 40 Ω/sq) electrode was deposited on the substrate by a face targeting sputtering process using an IZO target (90 wt% In_2O_3: 10 wt% ZnO). Prior to the deposition of organic layers, the substrate was cleaned with acetone and isopropanol. The cleaned substrate was then subjected to a UV-O_3 treatment for 15 min to reduce the energy level of IZO. The organic layers were deposited using thermal evaporation at a base pressure of 3×10^{-7} Torr in the following sequence: 1 nm-thick rhenium oxide (ReO_3) layers as hole injection layers (HILs), 175 nm-thick multilayers of 1,1-bis-(4-bis(4-methyl-phenyl)-amino-phenyl)-cyclohexane (TAPC) and 1,4,5,8,9,11-hexaazatriphenylene hexacarbonitrile (HATCN), a 10 nm-thick 4,4′,4′′-tris(carbazol-9-yl)-triphenylamine (TCTA) layer as the hole transport layer (HTL), a 30 nm-thick bis(2-phenylpyridyl) iridium(iii) acetylacetonate ($Ir(ppy)_2acac$) (8 wt%) doped TCTA and bis-4,6-(3,5-di-3-pyridylphenyl)-2-methylpyrimidine (B3PYMPM) co-host as the green phosphorescent emitter, 40 nm-thick B3PYMPM layer as an electron transport layer (ETL), a 1 nm-thick lithium fluoride (LiF) layer, and a 100 nm-thick aluminum layer as the cathode. A multilayer HTL was used to prevent leakage currents at the edge of the transparent electrode. The device was encapsulated in a glass canister.

3. Result and discussions

Fig. 2 shows the micrographs of the PS spheres spin-coated on the glass substrate and the air void optical scattering structures with 11 and 22 wt% HSQ. As seen from the SEM micrograph in Fig. 2(a), a monolayer of PS spheres with a diameter of 820 nm was coated on the glass substrate. Fig. 2(b) shows that the PS spheres formed a hexagonal close-packed array along with grain boundary-type defects. Fig. 2(c)