Organic Electronics 15 (2014) 3183–3190

Contents lists available at ScienceDirect

Organic Electronics

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

Solution-based nanostructure to reduce waveguide and surface plasmon losses in organic light-emitting diodes

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A R T I C L E I N F O

Article history:
Received 16 June 2014
Received in revised form 28 August 2014
Accepted 6 September 2014
Available online 19 September 2014

Keywords:
OLED
Out-coupling
Surface plasmon loss
Solution process
Nanostructure
Silica nanoparticle

A B S T R A C T

Organic light-emitting diodes (OLEDs) typically have low out-coupling efficiency. In this paper, a solution-based nanoparticle layer is presented as a nanostructure to enhance the out-coupling efficiency of OLEDs. Silica nanoparticles (NPs) are randomly distributed on indium tin oxide by spin-coating a silica NP solution. By further spin-coating poly(3,4-ethylenedioxythiophene)-poly(styrenesulfonate) (PEDOT:PSS) as a hole injection layer, a randomly corrugated PEDOT:PSS layer is fabricated. A nanostructured OLED having the corrugated PEDOT:PSS layer above the NP layer shows enhanced external quantum efficiency and power efficiency because the trapped light of the waveguide and surface plasmon modes is extracted by Bragg diffraction. The nanostructured OLED shows no angular dependence due to the broad periodicities of the corrugation. The simply fabricated and cost-effective silica NP layer nanostructure, which does not require a lithography step, has potential to enhance the efficiency of both white OLED displays and lighting.

1. Introduction

Organic light-emitting diodes (OLEDs) have become more popular in the display market and are now considered next-generation displays because of strengths including a broad color gamut, a fast response time, a lightweight form factor, thinness, and the possibility of flexibility compared with currently used liquid crystal displays. However, the external quantum efficiency (EQE) of typical OLEDs requires further enhancement. EQE is the internal quantum efficiency (IQE) multiplied by the out-coupling efficiency [1]. Although the IQE can reach nearly 100% using phosphorescence [2], a typical OLED has an out-coupling efficiency of only ~20%, with ~80% of the generated light being trapped as the substrate and waveguide modes from total internal reflection, and the surface plasmon mode from electron oscillation on the metal surface [3–5].

Many studies have attempted to enhance the out-coupling efficiency [3]. Several approaches, such as substrate modification [6] and the use of micro-lenses [7,8], have been introduced in efforts to reduce the amount of light trapped in the substrate. Among the various techniques reported to date, periodic corrugating on the metal cathode of OLEDs is an effective means of extracting specific wavelength light especially from the surface plasmon mode, the largest portion of trapped modes, in addition to waveguide modes by Bragg diffraction [9–15]. In particular, randomly nanostructured OLEDs with quasi-periodicity can enhance the out-coupling efficiency over broad wavelengths with a Lambertian emission pattern [16,17].

However, nanostructures fabricated by lithography [18,19] or an imprint method [20] cannot easily be adopted in large-area displays or for mass production because of cost issues and complicated processes, despite their high levels of efficiency. Thus, a simple solution-based method for an out-coupling layer has been studied [21,22].

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http://dx.doi.org/10.1016/j.orgel.2014.09.014
1566-1199/

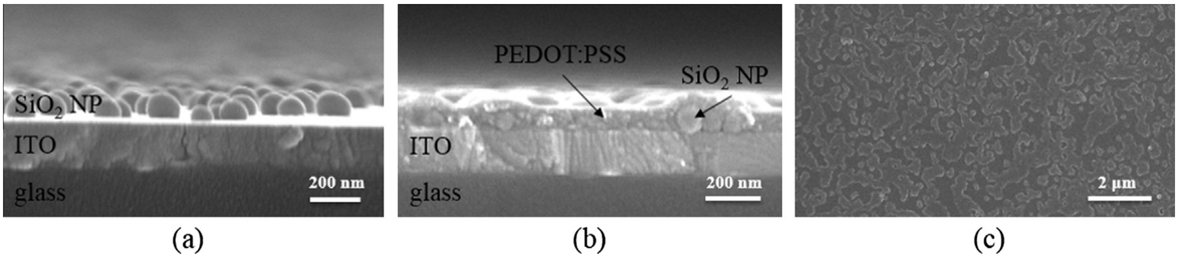

Fig. 1. SEM images of (a) randomly distributed silica nanoparticles on ITO layer, (b) corrugated PEDOT:PSS hole injection layer based on silica nanoparticles, and (c) surface of a randomly nanostructured Al cathode.

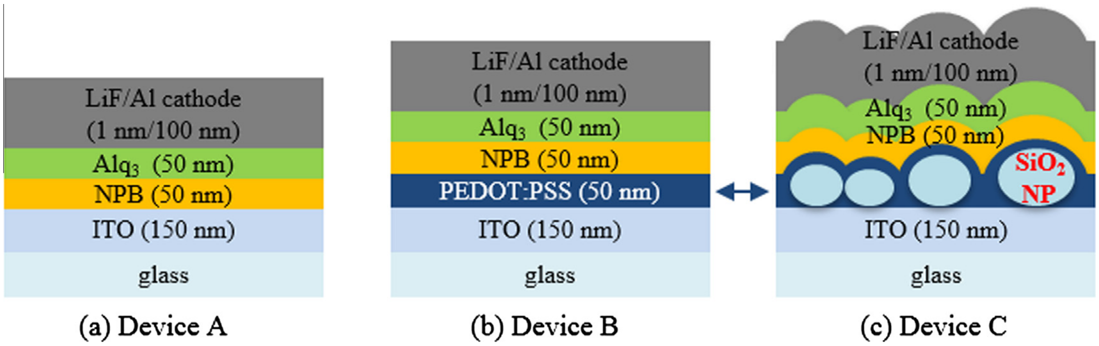

Fig. 2. Schematic illustrations of the devices used in this study: (a) flat OLED without a PEDOT:PSS layer (device A), (b) flat OLED with a PEDOT:PSS layer (device B), and (c) nanostructured OLED with a silica NP layer and a PEDOT:PSS layer (device C).

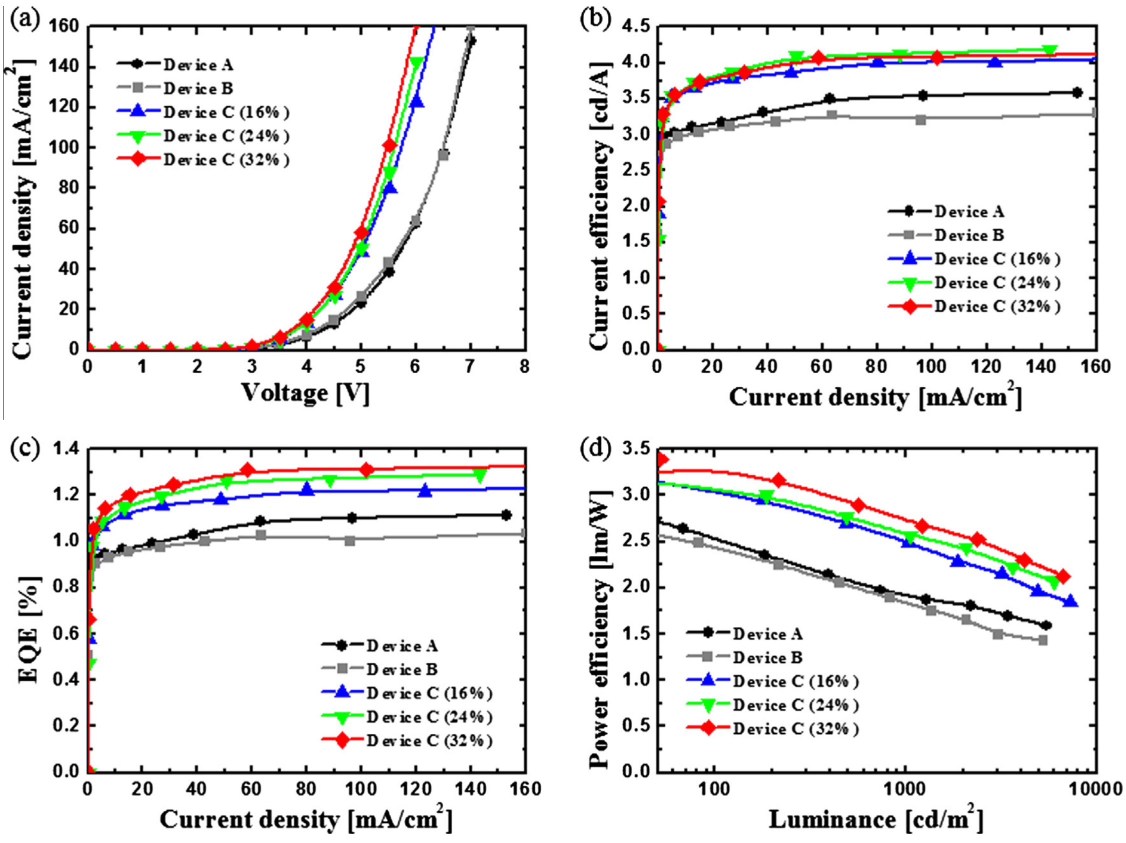

Fig. 3. OLED characteristics: (a) current density–voltage, (b) current efficiency–current density, (c) external quantum efficiency (EQE)–current density, and (d) power efficiency–luminance characteristics of devices A, B, and C from 16%, 24%, and 32% v/v synthesized silica NP solutions in ethanol.