Light Extraction Efficiency Enhancement in AC Driven OLEDs by Optimizing Layers Order and Thickness

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***Abstract* – In this study, refractive index and thickness optimization for each layer of Organic Light-Emitting Diode (OLED) are performed to provide light extraction efficiency for Alternating Current (AC) driven OLEDs. Firstly, the layer added on the active layer and defined as a hole injection layer is decided as polystyrene-block-poly methyl methacrylate (PS-PMMA). In the following, 13% enhancement of far field power, from 30% to 43%, is observed by setting the most proper thickness value. In addition, selection of suitable electron transport layer (ETL) and hole transport layer (HTL) increases the ratio of far field power to 65%. Finally, the thickness of indium tin oxide (ITO), selected as anode layer is optimally adjusted and total normalized power percentage is achieved as 67%. Particularly, enhancement of 13% in far field power by choosing the hole injection layer as PS-PMMA is pointed out in this paper.**

I. Introduction

OLEDs have actively studied in research and industry because of their low power consumption, high brightness and long lifetimes compared to conventional light sources [1]. Total internal reflection and the waveguide mode losses are the main factors which lead to the low light extraction efficiency of OLEDs [2]. Even though an internal quantum efficiency of almost 100% has been accomplished, the fraction of generated lights that is output into the front view of an OLED designed to manufacture on glass plane is around 20%. A variety of light extraction efficiency methods from the internal mechanism or the external pattern on the back surface of the substrate have been examined to increase light emission ratio such as structured and shaped substrates, scattering medium, microlens arrays, microcavity structure and photonic crystals [2].

As an external construction refinement method, a scattering medium layer improved with a roughened substrate has been proposed by Zhou *et al.*, and a 65% enhancement in the forward emission compared to a basic OLED without any scattering layer or roughened substrate has been obtained [2]. As an investigation on internal mechanism improvements Kalyani *et al.* have been synthesized different organic complexes and examined an unmixed and intense light emission with high efficiency [3]. As a result of this study, rare earth-based europium organic composites have been synthesized and then doped to polystyrene (PS) and polymethyl methacrylate (PMMA) polymers. Manufactured OLEDs has been provided a critical red emission at 612 nm and 10-18 V [3]. A solution-processed multi-layer quantum-dot-based LED has been investigated by Dai *et al.* and with the use of an insulating layer of PMMA, which has an external quantum efficiency of 20.5%. [4].

In this article, the main objective is to observe improvement in far field power when an organic layer is added on conventional OLED. According to this purpose, far field power and intensity profile are analyzed over optimum values with the comparison of preferably refractive index and arrangement of thickness.

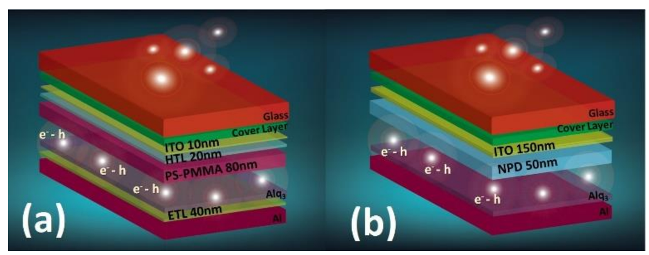

Fig. 1 (a) A conventional OLED structure and (b) modified organic layer on emissive layer and optimized ITO structure.

II. Methodology

Here, light extraction efficiency enhancement in AC driven OLED is studied by using finite difference time domain method [8]. First, the analysis focuses on the refractive index and the thickness of the hole injection layer. Next, the refractive index for anode and thickness is performed. Then, ETL and HTL are emphasized. In consequence of studies, analysis of far-field power and intensity profile in the visible region with chosen material for hole injection over tris (8-quinolinolato) aluminum (Alq_3) ($n \approx 1.66$), selected for the emissive layer where radiation occurs with electron-hole pair generation, are performed. It is observed that far field power increases proportionally while refractive index decreases. Hence, PS-PMMA diblock (n:1.14) copolymer whose refractive index is relatively quite low is chosen, Fig. 1[5]. PS-PMMA copolymer is a polymeric nanostructure resulting from phase separation effect during spin-coating of mixture solution consisting of PMMA and PS [6]. While this process, PS randomly distributed over PMMA creates a quasi-crystal like structure.

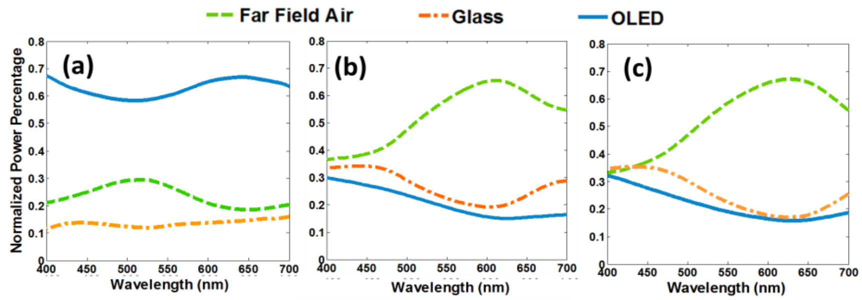

Fig. 2 (a) Far-field power for a conventional OLED structure, (b) structure modified organic layer on the emissive layer and (c) OLED structure with optimized ITO.

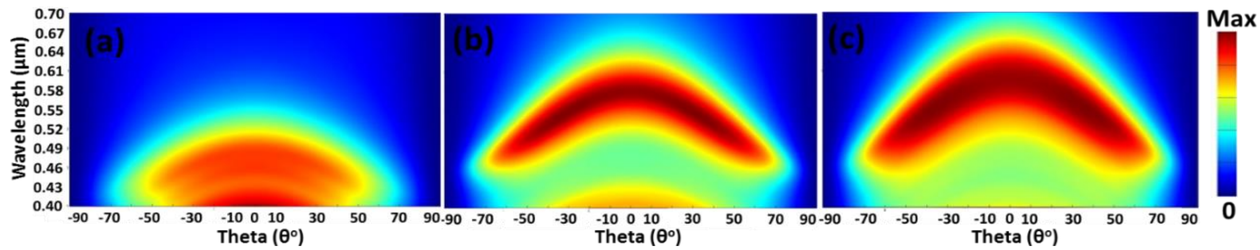

Fig. 3 (a) Intensity profiles for conventional OLED structure, (b) structure modified organic layer on the emissive layer and (c) OLED structure with optimized ITO.

Scattering effect of created quasi-periodic structure generates corrugated microcavity. Hence it reduces loss occurred in surface plasmon polariton (SPP) modes and wave-guided modes [7]. The increment in far field power by means of using PS-PMMA could be explained by suppression of loss mechanism mentioned above. Also, thickness optimization of PS-PMMA material suited as a hole injection layer is also considered in order to get more exploitation and several studies on setting the most proper thickness value are researched. These studies demonstrate that the mechanism which triggers the increment of far-field power is not only the refractive index of the material of the emissive layer but also the thickness of that material. Thus thickness of PS-PMMA is set to 80 nm and percentage of enhancement in power spectrum is seen as 13%, from 30% to 43%. In addition to this, ETL and HTL enabling of hole and electron transition to the active layer is selected as Lithium Fluoride (LiF) (n ≈1.4) and molybdenum oxide (MoO_3) (n ≈1.8), respectively. The decision of optimal thickness of 40 nm for ETL nm and 20 nm for HTL provides ~22% increase in far field power, from 43% to 65% [9]. Finally, metal and ITO are compared for anode material selection and because of transparency and electrical conductivity transparent conducting oxide ITO is chosen and studies on thickness optimization of this layer are emphasized. Setting 10 nm ITO for anode layer indicates just 2% increment in far field power, from 65% to 67%.

III. Conclusions

In conclusion, ETL and HTL effect for chosen optimum material and thickness is concluded as ~22%. From far field power results in Fig.2 and intensity profiles in Fig.3, the addition of ETL, HTL and decrease of ITO thickness also triggers radiation in broad wavelength spectrum and broad angles. SiN (n=1.9), last layer before the glass, is used as the cover layer and provides the more smooth light transition from ITO to the glass. In contrast with known conventional OLED designs, PS-PMMA material having quasi-crystal like structure acts as hole injection layer and enhances 13% in far field power spectrum.

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