Efficiency Enhancement of OLED by Extracting Guided Modes

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***Abstract* – The effects of the structural parameters of the photonic crystal (PC) placed between glass and indium tin oxide (ITO) for an efficient organic light-emitting diode (OLED) design is studied. It is shown that the light extraction efficiency of OLEDs varies with the PC height and period. The maximum relative extraction efficiency (EE_r) value is obtained at 0.4 µm PC height and 0.36 µm period.**

I. Introduction

OLEDs have a remarkable influence on technology applications such as large scale displays and lighting devices with their low production cost, perfect color gamut, low power consumption, high illumination efficiency and long lifetimes [1]. However, the light extraction efficiency of OLEDs is becoming too low due to internal total reflection and the waveguide mode losses [2-3]. In OLEDs, light generates from organic layer and only half of it is captured within ITO-Organic waveguide. Following, only %20 of the generated light is effused from the glass-air interface. In order to improve light extraction efficiency ratio in OLEDs, many methods have been examined such as PCs, low index grids, microlens arrays, random scattering layer and shaped substrates [4,5]. In Ref. 5, Kim *et al*. analyze the nano-sized layer to investigate the absorption coefficient and the light extraction efficiency. They present a new design by placing a scattering layer consisting of glass or silica and buffer layer under the ITO. Due to this structure, they increase external quantum efficiency by a factor of 1.8. Do *et al*. provide two-dimensional SiO_2/SiNx PC layer to enhance the light extraction efficiency [6]. They optimize the PC inserted at the interface between anode and glass substrate in terms of periodicity and achieve %50 enhancement of light extraction efficiency. Most of these methods have been tried to minimize the total internal reflection while changing contact surface of the glass substrate with the organic device [2-7]. Many techniques have been developed by different researchers for the same goal.

II. Design and Analyses

In this study, the effect of periodicity and height of a PC located in between the anode (ITO) and the glass substrate is investigated. The layer of the designed OLED structure demonstrated in Fig. 1 and its thicknesses are given as follows: Aluminum cathode (0.6 µm), as an emissive layer Tris (8-hyroxyquoinoline) aluminum (Alq3) (0.06 µm), N,N´-di(1-naphthyl)-N,N´-diphenyl benzidine (aNPD) conductive layer (0.05 µm), ITO anode (0.15 µm), cover layer SiN (0.07 µm), substrate glass (3.72 µm). A one-dimensional periodic structure consisting of SiN material is placed on the cover layer. In order to model the emergent photons in the emissive layer, the dipole source is used in the analysis. Numerical calculations are obtained using finite-difference time-domain (FDTD) method [8].

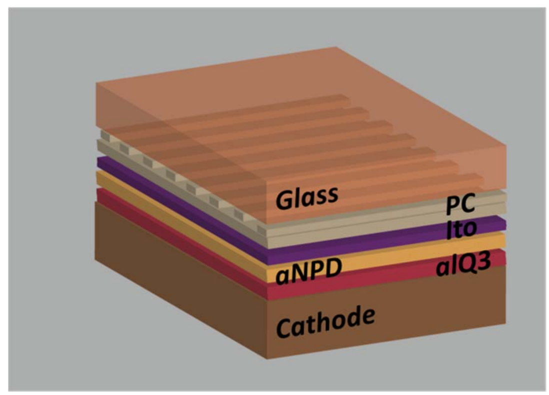

Figure 1. The schematic representation of OLED design

Our aim is to observe the change in relative light extraction efficiency when the photonic crystal's thickness is increased from 0.1 µm to 0.5 µm in the y-axis. In Fig. 2 (a), the extraction efficiency enhancement when the photonic crystal's thickness is 0.1 µm and 0.4 µm can be seen. The relative extraction efficiency is calculated by the ratio of the far field emitted power of structure with PC and without PC. In OLEDs, extraction efficiency depends on the wavelength and adding PC enables relatively higher light extraction in specific wavelengths. Besides by changing structural parameters of the embedded PC, the wavelength value the maximum enhancement is obtained at can be adjusted. In Fig. 2(a), it is clear that the maximum extraction efficiency enhancement value is obtained at 0.628 µm wavelength when the thickness of the PC is 0.4 µm. In order to analyze the effect of the periodicity of a PC on extraction efficiency, PC height is fixed to 0.4 µm and different PCs with various periodicity are embedded. When analyzing the effect of periodicity, values between 0.3 µm and 0.72 µm are swept and corresponding enhancement value is calculated. The results of two cases of those trials have been stated in Fig. 2(b). It is observed that

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likewise varying the thickness of the PC, changing periodicity can provide us the wavelength value where the enhancement is ensured. After all, the best improvement is achieved when the period equal to 0.36 µm.

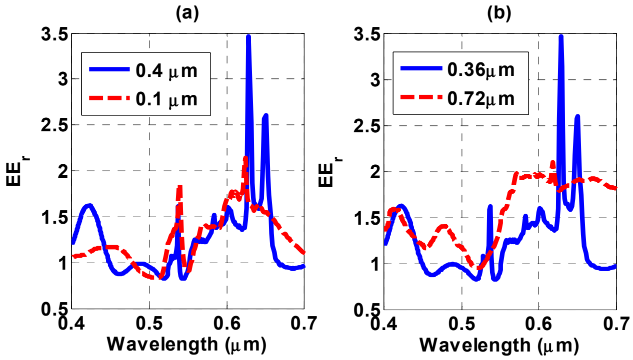

Figure 2. (a) The relative light extraction efficiency (EE_r) of two different OLED design. The solid blue line shows 0.4 µm PC height and dotted red line shows 0.1 µm PC height (b) The EE_r of two distinct OLED design. The solid blue line shows 0.36 µm PC period and dotted red line shows 0.72 µm PC period

In order to observe the effect of adding a PC layer, electric field distribution is also plotted. In Fig. 3(a), the electric field inside a conventional OLED that is created by the source is shown. After the light emerges in the emissive layer, light is reflected back to the metallic cathode then radiates passing through the layers and reaches the glass substrate. However, when passing through the layers and the substrate, light is trapped which causes loss of energy. One of these losses occurs between ITO (n=1.8) and glass (n=1.46) transition. Since ITO layer has a higher refractive index than glass, incident light is totally internally reflected. The modes that reflected internally are guided inside ITO layer and escape from OLED's side surfaces. The main purpose of inserting a PC is to decrease index mismatch between glass and ITO layer so that the losses caused by total internal reflection will be lessened. In Fig. 3 (b), the electric field distribution can be seen when 0.4 µm-height with the periodicity of 0.36 µm PC is inserted. The added structure reduces the losses due to the guided waves by having the scattering effect on the electric field. PC also allows the light to be transmitted far-field by providing directional emission. Another advantage of the periodic nature of the PC we inserted is that it allows frequency adjustment since it provides a filtering effect.

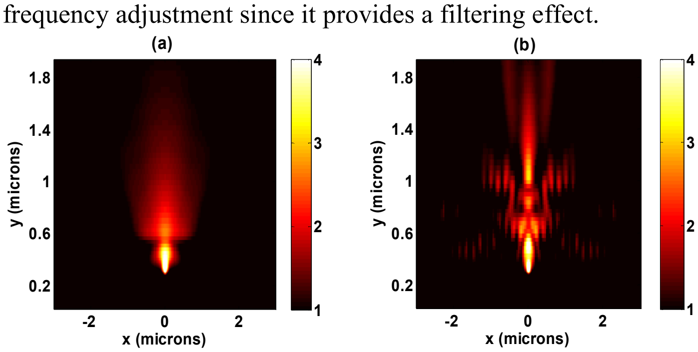

Figure 3. (a) The electric field distribution in OLED design with (a) no PC and (b) PC structure.

III. Conclusions

In conclusion, it is presented that changing structural parameters of the PC makes light extraction efficiency possible to be improved compared to the conventional OLEDs. In addition to this precious outcome, it is also found out that we can adjust the frequency value where the optimum improvement can be achieved.

Acknowledgment

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