Investigation on the Effect of Applying Different Structures on OLED Devices to Its Performance and Quality

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Abstract. OLED is a kind of device that contains multiple organic layers to produce electroluminescence. OLED has the benefit such as the easy process of manufacturing and only needs a low driving voltage which is environmentally friendly. OLED has low thickness and it doesn't cost a lot of power compared with LED. By making it as a screen, it can be flexible and have a high capability to emit high light intensity. In this case, more and more experts and enterprises are developing and investigating more in this field. Nowadays, OLED is widely used in the manufacture of foldable screen on mobile phones. Besides, OLED still has a huge room to improve. The external quantum efficiency (EQE), which is the ratio of electrons collected to the incident photons, was well acknowledged to be a good indicator for researchers to evaluate the performance in OLED devices. Due to the difficulties on significant improvement on materials used to make OLED, experts put their effort on designing better structures for OLED to increase its percentage EQE. Therefore, in this work, the performance of OLED devices with different structures were compared.

Keywords: OLED performance, Structures, Graph analyzing.

1. Introduction

Over the past few years, displaying devices have gained great attention since it related to both the living standard of humans and the efficiency and accuracy on almost all types of jobs. Then, light emitting diode becomes further developed while in the recent years. OLED which the material used is granite substance gained significant attention by scientists since it does have more space to improve by improving material performance and structures to increase efficiency. Emissive OLED displays are gaining momentum, fiercely competing with LCDs in TVs and smartphones due to their superior, unprecedented dark state, slim profile and free-form factor [1]. OLED includes the phenomenon of light emission caused by the injection and recombination of charge carriers inside its structure, and its emitting light intensity is directly proportional to the amount of current passing through. With the help of electric field, the holes generated by anode will move downwards to the hole transport layer while the electrons generated by cathode will move to the electron transport layer. The electrons and holes will finally meet each other at the emission layer. Therefore, it can generate energy exciton, which excite the light emitting molecules and eventually produce visible light. In this essay, the structures of OLED will be focused more and find an optimum way to achieve some light emitting action or more environmental method to emit light. The first experiment will focus more on the rate of luminance increasing as voltage increases in varied MLA and gating of OLED while also find the trend of change in percentage EQE as the luminance rises in MLA with different thicknesses and gating of OLED for different period of time. The second experiment is divided into two parts with group of blue/red ratio to investigate the optimum ratio for further investigation. Then, we can change the spacer thickness between each component and find a best one by testing all the data in the OLED performance. These two experiments compared the effect on the external quantum efficiency of OLED devices by using different structures, since they have focused on different fields to improve the structure. The following paper will describe the difference in results and reasons for changing MLA & gating and spacer thickness.

2. Different structures applied to assemble the OLED device

2.1. ITO glass and evaporation system (experiment 1)

The first example uses an automatic Cluster evaporation system made in Japan, which make it available for light extraction performance of composite structures and green logic OLED testing for evaporation OLED devices. Firstly, the operator sonicated the ITO glass substrate with deionized water, acetone, ethanol for 15 minutes [2]. It is then dried with nitrogen under heat; After drying, the as-cleaned ITO glass substrate was placed in an evaporation system. After the degree of vacuum in the deposition cavity becomes low, the materials of the OLED functional layer and the luminescent layer are vaporized and deposited on the anode substrate at a rate of 0.1 nm/s. Green OLED Structure: ITO / HAT-CN (15nm) / TAPC (60nm) / TCTA (10nm) / MADN: 3%DSA-PH (20nm) / TPBi (45nm) / LiF (1nm) [3].

2.2. NPB and TPBi radial group complex (experiment 2)

The photoluminescence (PL) spectra of NPB, TPBi and NPB: TPBi were measured at room temperature, and NPB: TPBi was doped at a mass ratio of 1:1 to verify the formation of NPB: TPBi radial group complex. The absorption spectra of Ir(DMP-IQ)$_2$(acac) films were measured and compared with the PL spectra of Radial group complexes to investigate the energy transfer between them.

In order to investigate the device performance based on the formation of radial group complexes at the interface of NPB and TPBi, the device structure designed in experiment 2 is as follows. Device A is ITO/NPB(50nm)/Ir(DMP-IQ)$_2$(acac)(0.5nm)/TPBi(20nm)/Liq(1nm)/Al(100nm) [4], where 50nm refers to the thickness of NPB. Device B is ITO/NPB:15%MoO$_x$(50nm)/TCTA(10nm)/NPB: 3%Ir(DMP-IQ)$_2$(acac)(20nm)/TPBi(20nm)/TPBi:20%Liq(20nm)/Al(100nm), where 15% MoO$_x$ is molybdenum oxide in this functional layer mass ratio is 15%, TCTA is 4,4',4″-tris (carbazol-9-yl) triphenylamine. In order to study the properties of a device based on an exciton complex formed by doping NPB and TPBi, the structure of the device was developed as follows. Device C is ITO/HAT-CN(20nm)/NPB(20nm)/NPB：TPBi(1:1, 10nm)/Ir(DMP-IQ)2(acac)(0.5nm)/TPBi(30nm)/Liq(1nm) /Al(100nm) where 1:1 refers to the mass ratio NPB: TPBi is 1:1 and HAT-CN is dipyrazino [2, 3-F: 2', 3'-h] quinoxaline-2, 3, 6, 7, 10, 11-hexacarbonitrile. Based on a device formed by doping NPB and TPBi, x thick TPBi was evaporated between the exciton complex and the red phosphorescent luminescent layer as a spacer layer. The structure of the device is as follows. Device D manufactured based on device C but change the thickness of TPBi in a range of 10-40 nm. The electroluminescence spectra of the devices produced in this way show different ratios of red/blue light at different thicknesses of the spacer, thereby achieving the goal of adjusting the ratio of the blue-red spectrum. In order to reduce exciton quenching caused by excessive accumulation of exciton in the NPB: TPBi layer, the mCP base material is embedded in the NPB: TPBi layer, thereby forming a ternary system.

3. Method and Data Analyze

3.1. Optical extraction performance in experiment 1

Then, the different structures were pasted on the glass substrate of the OLED device with refractive index matching solution, and the optical extraction performance was tested in laboratory environment. Figure 1 shows the performance of green OLED devices with different structure applications. It can be found from Figure 1 (a) that the J-V characteristics of OLED devices under different heights of micro-lens arrays are almost the same, indicating that the introduction of micro-lens arrays into OLED devices has almost no impact on the electrical performance of devices, and the slight difference in L-V curves can be attributed to the change of output coupled light. Figure 1 (b) shows the influence of different heights of micro-lens arrays on the external quantum efficiency of OLED devices. It can be found that the external quantum efficiency of OLED devices can be improved only when the height of the micro-lens array is about 19.6 μm [10]. The external quantum efficiency of the device decreases to a certain extent with other high micro-lens arrays. When the voltage is 8V, the EQE of the OLED device is 8.47%, and the EQE of the OLED device is 9.18% when the height of the micro-lens array is 19.6μm. The external quantum efficiency improves by about 8.38%. A 19.6μm micro-lens increases the critical angle of total internal reflection and also decreases the total internal reflection of the air interface and affects light output more significantly than a micro-lens of a different height. However, larger micro-lens arrays require multiple spin coating processes, resulting in more complex processes and not facilitating structure preparation. Therefore, when the height of the micro lens is about 19.6μm, the external coupling effect of the micro lens array is relatively better. The light extraction properties of nano-grids and composite structures have been studied. It can be seen from Figure 1 (c) that J-V characteristics of OLED devices under nano-gratings and composite structures are almost the same, indicating that the introduction of nano-gratings and composite structures into OLED devices has almost no effect on the electrical characteristics of the devices, and the slight difference in L-V curves can also be attributed to the change of output coupled light. Figure 1 (d) and Figure 1 (c) corresponding to the external quantum efficiency (EQE) of OLED devices under the structure show that the performance of the devices with long period and large depth nano-gratings obtained by argon plasma processing is not improved compared with that of OLED devices alone. On the contrary, there is a certain degree of decline. The optical coupling efficiency of OLED devices may be affected by the large depth and period of the nano-gratings prepared by argon plasma processing. Compared with the OLED device alone, the EQE of the OLED device based on the composite structure of nano-grating and micro-lens array obtained by oxygen plasma processing is improved. At the same voltage of 8V, the EQE of pure OLED device and micro-lens array/nano-grating composite OLED device are 8.47% and 11.26%, respectively, and the enhancement effect can reach 1.33 times. This may be because the short-period and shallow depth nano-gratings prepared by oxygen plasma system can effectively increase the duty cycle of the micro-lens array and reduce the total reflection of green light at the interface between the micro-lens and air. Therefore, the composite structure of micro-lens array/nano-grating can improve the light extraction efficiency of green light OLED devices. It is worth noting that when the stretching degree increases and the period of the nano-grating becomes smaller, the light extraction efficiency is expected to be further improved. However, the deformation in the direction perpendicular to the tensile direction also increases, so more cracks will be generated by the nano-gratings, which may have a certain impact on the optical extraction performance [6].

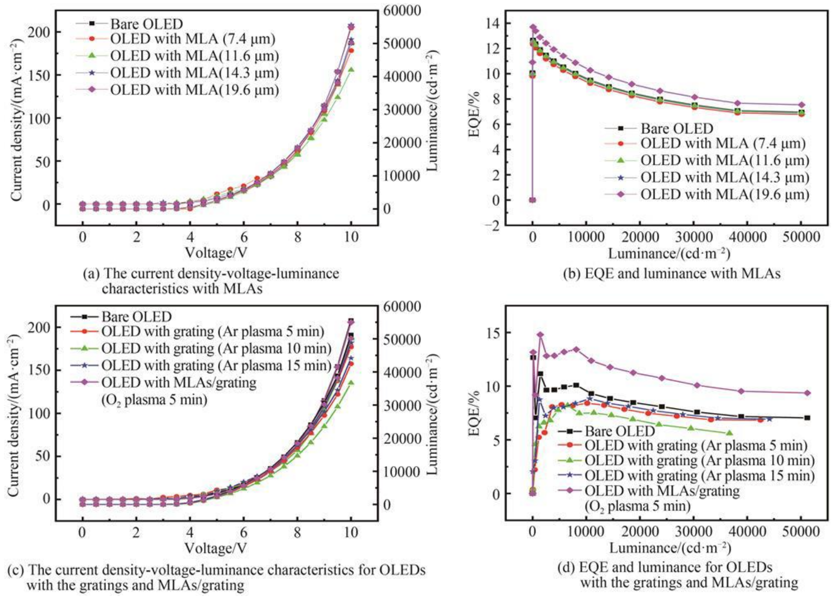

Figure 1. (a) (c). The trends of increasing voltage to the light intensity of OLED with different gating or MLA, (b)(d). The percentage EQE against the luminance of OLED with different gating or MLA [6]

3.2. Adjusting on thickness of components to the performance of OLED in experiment 2

OLED devices based on the NPB/TPBi interface for generating deep blue excimer complexes have high brightness and efficiency, but from the normalized EL spectrum of the device, the ratio of blue and red light intensities (blue/red ratio) limits the practical application of such OLEDs in the field of horticultural lighting sources. Artificial light sources should be well designed and prepared with different blue/red ratio light-emitting devices according to the requirements of different plant growth stages in the blue-red spectrum. A spacer was introduced between $Ir(DMP-IQ)_2(acac)$ layer and NPB: TPBi layer. The blue/red ratio of EL spectrum was adjusted by changing the energy transfer distance between the layer and the red phosphorescent material of that. The energy level diagram of device C is shown in Figure 2(a), and the EL spectrum is shown in Figure 2(b). In device C, the exciton complex is generated in the NPB and TPBi doped layer, and the resulting deep blue light exciton complex partially transfers its energy to the layer, resulting in a red-light emission peak at 640 nm. Thus, devices with similar EL spectra as devices A and B are obtained, with A brightness of 1925 cd/m^2, a maximum current efficiency of 1.69 cd/A, and also reach a maximum EQE of 1.21%. By analyzing the EL spectrum of device C, it can be seen that its blue/red ratio is significantly higher than that of device A and B, indicating that the blue/red ratio of its EL spectrum can better meet the requirements of plant lighting source. Based on this structure, TPBi of different thickness was plated between the doping layer and thin film as spacers, and the blue/red ratio of luminescence spectrum was adjusted by changing the amount of blue light energy absorbed by the thin film [7]. These devices are named D1, D2, D3, and D4, depending on the spacer thickness (1-4 nm) Figure 3(a) and Figure 3(b) show the change in EL spectra of devices D1~D4 and the luminescence colors of corresponding devices. The performance parameters of devices A~D are shown in Table 1. From Figure 3(a) and Figure 3(b) it can be seen that the blue/red ratio increases with the thickness of the spacer. As the spacer thickness increases beyond 2 nm, the electroluminescence spectrum of the device changes from red to blue, and the electrical properties of devices with different spacer thicknesses also show the difference [8]. In combination with Figure 3 and Table 1, it can be seen that the brightness of the device gradually increases as the pad thickness increases. The maximum brightness of D1, D2, D3 and D4 is 1881, 2079, 2365, 2475 cd/m^2 respectively. The increase in brightness is caused by an increase in intensity of higher energy blue light. The opening voltages of D1, D2, D3 and D4 are 3.6, 3.5, 3.6 and 3.8 V, respectively. It can be seen that the spacer has little effect on the opening voltage of the device. When further increasing the spacer thickness to 5, 10, and 15 nm, the EL spectra of the respective devices remain practically unchanged, as shown in Figure 3(c), which means that the maximum energy transfer distance of the exciton complex, NPB: TPBi doping, 4 nm is more than 4 nm. The energy of the excimer is practically not transferred to the red phosphorescent material.

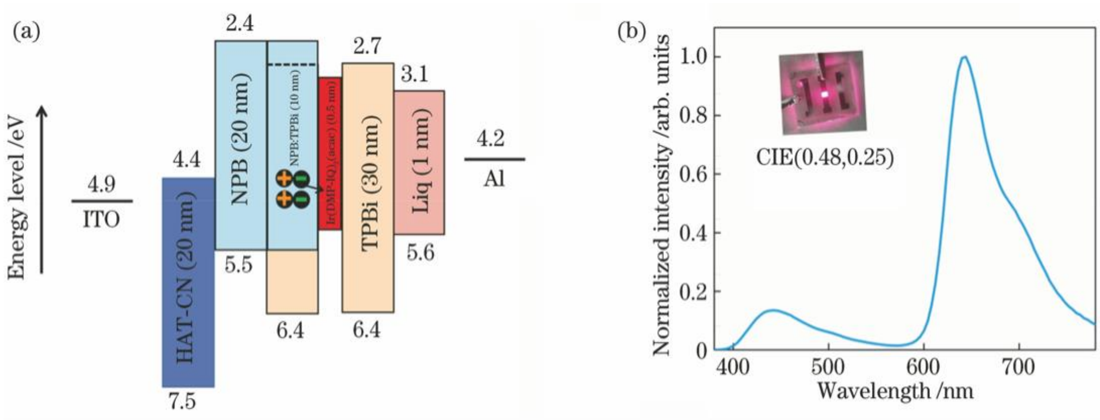

Figure 2. The structure of OLED with NPB and TPBi group complex [9]

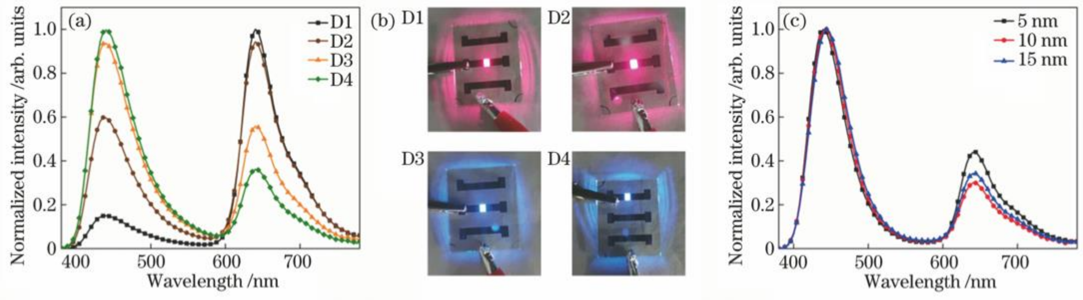

Figure 3. The normalized intensity of OLED in different wavelength (red and blue light) [9]

Table 1. Analyzed the different performance tested in the experiment 2 [10]

Device	V_{on}/V	L_{Max}/(cd·m^{-2})	Maximum CE(cd·A^{-1})	Maximum EQE/%	EQE/%
A	3.7	2101	1.02	1.97	1.82
B	5.1	5390	3.36	6.80	5.72
C	4.0	1925	1.69	1.21	0.35
D1	3.6	1881	0.92	2.04	1.99
D2	3.5	2079	1.62	3.70	2.52
D3	3.6	2365	2.13	4.33	1.68
D4	3.8	2475	1.02	2.40	1.81

4. Conclusion

This work shows that the heights of micro-lens arrays, nano-gratings and composite structures have nearly no influence on the electrical performance of devices. However, the external quantum efficiency of OLED devices increases while the micro-lens is adjusted to the optimum height. Also, by using the nano-gating and composite structures obtained by oxygen plasma processing, the external quantum efficiency can also be improved. In contrast, the effect of using the nano-gating and composite structures obtained by argon plasma processing is opposite which the effect is even worse. The device which the exciton complex is generated in the NPB and TPBi doped layer has a resulting deep blue light exciton complex that only partially transfers its energy to the Ir (DMP-IQ)2(ACAC) layer. By investigating this device, the ratio of red light and blue light shows its significance. The next experiment adjusted the spacer thicknesses of each device and compared their maximum voltage and light intensity. It can be seen that the thicker the space between each component, the higher the voltage capacity and intensity of light emitted. However, it is limited to increase the thickness as large as possible. Beyond a certain value, the components will lose their sensibility since the gap is too large.

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