

阴极耦合层对顶发射白光OLED器件光电性能影响

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Effect of refractive index matching layers on optical and electrical properties of top-emitting organic white light emitting devices

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Abstract: In order to analyze the effect of different thickness of C60 on optical and electrical properties of top-emitting OLED, in experiment, the transmittance of ETL/EIL/Mg:Ag/matching layers were numerically calculated and two top OLED with common cathode configurations were fabricated. The optical and electrical properties of OLED devices prepared with different thickness of C60 refractive index matching layers were analyzed. The results showed, the complex films with different C60 thickness have different transmittance, the complex films have high transmittance in wide range of wavelengths when C60 film thickness is 30~40 nm, the CIE_x and CIE_y values of transmittance spectra are extremely near to the equal energy (0.33,0.33). In addition, it can be found that the electroluminescence spectra and the chromaticity coordinates of OLED devices are also heavily related to the thickness of C60 refractive index matching layers, which is consistent with the numerical results of transmission spectrum of multilayer (ETL/EIL/Mg:Ag/C60) at different thickness of C60 thin films and indicate that the luminous brightness and the color coordinates of top-emitting white light devices can be adjusted by different thickness of C60 refractive index matching layer to achieve white light emission close to equal energy.

Key words: organic white light emitting devices; top-emitting; transfer matrix; outcoupling layer

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阴极耦合层对顶发射白光 OLED 器件 光电性能影响

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摘要:为了研究不同厚度 C60 阴极耦合层对顶发射白光 OLED 器件光电性能的影响,实验数值计算了半透明阴极组成的多层膜系(ETL/EIL/Mg:Ag/C60)的透过率;同时,采用共阴极结构设计制备了顶发射白光 OLED 器件,并对不同厚度的 C60 折射率匹配层制备的顶发射白光 OLED 器件的光电特性进行了研究。结果表明,不同 C60 厚度的多层膜系透过率差异较大,在 C60 膜层厚度为 30~40 nm 时,多层膜在较宽波段范围内均有高的透过率,且透过率光谱的色坐标最接近白光等能点;通过分析不同阴极耦合层制备的顶部发光 OLED 器件的光电性能,发现采用适当厚度的 C60 阴极耦合层材料,可以有效提高器件外量子效率,并在一定程度上能够有效改善器件的色坐标,实现接近等能白光的顶发光 OLED 器件制备。

关键词:有机发光器件;顶部发光;转移矩阵;光萃取

中图分类号:TN383+.1 **文献标识码:**A **doi:**10.3788/YJYXS20203505.04222

1 Introduction

OLED displays have special advantages such as high resolution, fast response and self-illumination, it is recognized as next-generation display technologies^[1-3]. The light is emitted from the top of the device of the top white-emitting OLED devices, white light emitting devices solve the competition between the pixel drive circuit and the emitting area of devices, improves the aperture ratio and easily obtains high-resolution or high-brightness OLED devices^[4-5]. The brightness of the OLED devices can be maximized by increasing the light extraction efficiency by specifically using metals with high reflectivity as bottom electrode and the transparent or semitransparent materials as top electrode. However, the microcavity effect caused by the re-

flection of metal electrodes have an important effect on the photoelectric properties of top light-emitting OLED devices^[6-8]. The color coordinates of the OLED device shift according to the change of viewing angle and gradually deviate from white (0.33, 0.33), which limits the practical application performance of illumination and display.

In this paper, the multilayer anode (Al/Mo/MoO₃) with high reflectivity and low electrical resistance was prepared on the glass substrate by thin films deposition method. The C60^[9-10] transparent conductive oxide layer was prepared as index matching layer to improve device extraction efficiency. In this experiment, the transmission and loss (absorption and reflection) of ETL/EIL/Mg:Ag/C60 were calculated based on the transfer matrix theory and the optical constants of the material, and the influence of C60 was systematically analyzed.

2 Experiments

The OLED devices were prepared on glass substrate. The substrate was ultrasonically washed by acetone, alcohol and deionized water successively. Metal multi-layers anodes were prepared by thermal evaporation system. Then the OLED devices were fabricated by the thermal evaporation of the organic materials. The film layers were deposited by vacuum vapor deposition at $< 2 \times 10^{-4}$ Pa. OLED device structure is metal anode (60 nm) /HIL(15 nm)/HTL(10 nm)/EML(20 nm)/ETL(15 nm)/EIL (10 nm) LiF(1 nm)/Mg : Ag(10 nm)/C60 (35 nm). The C60 film is used as the out-coupling layers and encapsulation layers. The active area of OLED is controlled at 20 mm². The electroluminescence spectra is measured using the PR655, the luminance current versus voltage characteristics are measured simultaneously with the Keithley 2400.

3 Results and Discussion

3.1 Transmission and chromaticity coordinate of transmission spectrum of multilayer (ETL/EIL/Mg/Ag/C60) thin films

C60 thin films is firstly used as the out-coupling layer on the surface of cathode to improve the external quantum efficiency of top-emitting organic light emitting devices as a result of it's high transmittance and refractive index in visible light spectrum. The extinction coefficient (k) and refractive index (n) of C60 thin films is tested with spectroscopic ellipsometry and showed in Fig.1. It can be seen that the extinction coefficient (k) and refractive index (n) is high at short wave, but in visible light spectrum the refractive index (n) is higher than 1.5, the extinction coefficient (k) is close to 0 from the Fig.1. The relationship between the extinction coefficient and the absorption coefficient is:

$$\alpha = \frac{4\pi k}{\lambda}, \quad (1)$$

the higher of k , the stronger of α , the C60 films is very suitable for refractive index matching layers of top-emitting OLED.

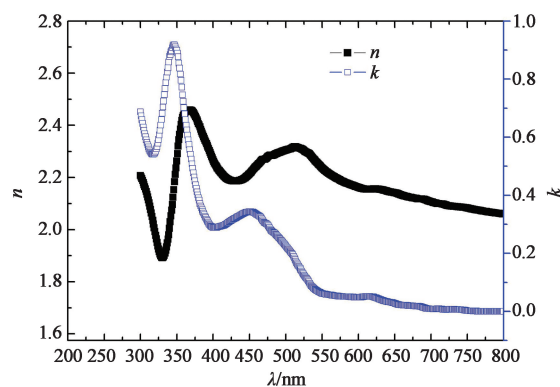
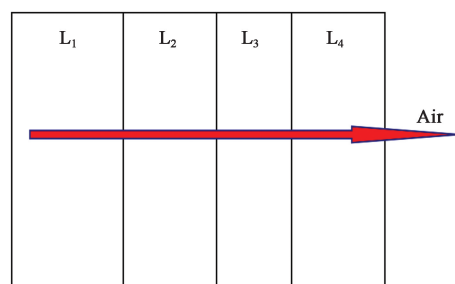


Fig.1 Extinction coefficient (k) and refractive index (n) of C60 thin films



L_1 : electron transport layers; L_2 : electron inject layers; L_3 : Mg/Ag; L_4 : outcoupling layer

Fig.2 Structure of multi-layers thin films

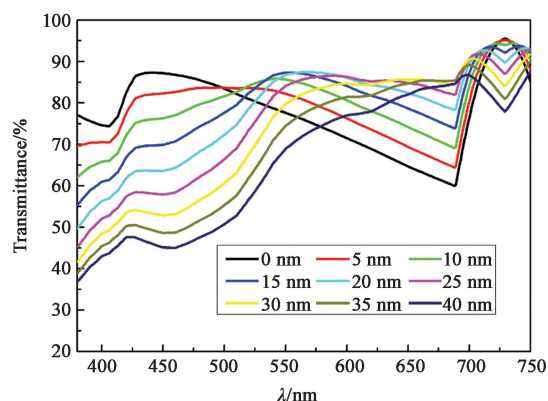


Fig.3 Transmission spectra of multilayer (ETL/EIL/Mg : Ag/C60) at different thickness of C60 thin films

In order to evaluate the effect of ETL/EIL/Mg : Ag/C60 on optical and electrical properties of top-emitting organic white light emitting devices, based on relevant theory, the transmittance of the multilayer films were simulated by matlab, the structure of multi-layers thin films is showed in Fig. 2. The transmission spectra of multilayer thin films (ETL/EIL/Mg : Ag/C60) at different thickness of C60 are illustrated in Fig. 3. The experimental results showed that the transmission of multilayer thin films (ETL/EIL/Mg : Ag/C60) gradually increase according to the increase of C60 thickness of

cathode refractive index matching layers, and the transmission in the entire visible range gets to the maximum, when the C60 thickness is controlled at about 30 nm or 40 nm, hereafter the transmission in turn gradually decrease, which confirmed the truth of the obviously effect of C60 thickness variations on the transmission of multilayer (ETL/EIL/Mg : Ag/C60).

The chromaticity coordinates of transmission spectrum of multilayer (ETL/EIL/Mg : Ag/C60) at different thickness of C60 were calculated and were listed in Table 1.

Tab.1 Chromaticity coordinates of transmission spectra of multilayer (ETL/EIL/Mg : Ag/C60) at different thickness of C60

Number	ETL thickness/ nm	EIL thickness/ nm	Cathode thickness/ nm	C60 thickness/ nm	CIE _x	CIE _y
1	15	10	10	0	0.314	0.323
2	15	10	10	5	0.323	0.334
3	15	10	10	10	0.334	0.345
4	15	10	10	15	0.345	0.355
5	15	10	10	20	0.356	0.362
6	15	10	10	25	0.365	0.366
7	15	10	10	30	0.373	0.368
8	15	10	10	35	0.378	0.369
9	15	10	10	40	0.381	0.368
10	15	10	10	45	0.382	0.366

From the Table 1, we can see that the thickness variations of C60 refractive index matching layers have heavily effect on the chromaticity coordinates of transmission spectrum of multilayer, and the CIE_x or CIE_y obviously changes. It is also found that when the thickness variations of C60 refractive index matching layers gets to 30 nm or 40 nm, the CIE_x and CIE_y value are extremely near to the white equal energy (0.33,0.33), which is demonstrated that to some extent the thickness is not only related to the transmission, but influences the chromaticity coordinates of transmission spectrum of

multilayer (ETL/EIL/Mg : Ag/C60). When the thickness of C60 refractive index matching layers are controlled at appropriate value, the transmission of multilayer (ETL/EIL/Mg : Ag/C60) will get to the top and have almost no effect on the chromaticity coordinates of electroluminescence spectra of top-emitting organic light emitting devices.

3.2 Optical and electrical properties of top-emitting organic white light emitting devices

Two top organic white light emitting devices with common cathode configurations were fabricated, and the optical and electrical properties

of OLED devices prepared with different thickness of C60 refractive index matching layers were analyzed. The optical and electrical properties of OLED devices prepared with different C60 thickness at the current density of 20 mA/cm^2 were shown in Table 2. It can be seen from the Table 2, the sample 1 # and sample 2 # have the same driving voltage, but differs in brightness, effectiveness, and chromaticity coordinates at the current density of 20 mA/cm^2 . It illustrated that the OLED devices with different thickness of C60 refractive index matching layers have no effect on the electrical properties, but

have obviously effect on optical properties. As far as we know, the I - V characteristic of OLED devices mainly depend on an electrode material, organic layer and the interface characteristics in devices, so the refractive index matching layers or thickness variations is not related with the inject, transport, recombination of carriers and produce photons. Consequently, the color of the emitted light, depends on the electronic properties of the organic material in which the photons are generated^[11]. The experimental results are consistent with the carriers transport mechanism.

Tab.2 Optical and electrical properties of OLED devices prepared with different C60 thickness at the current density of 20 mA/cm^2

Sample	C60 thickness/nm	Voltage/V	brightness/ ($\text{cd} \cdot \text{m}^{-2}$)	effectiveness/ ($\text{cd} \cdot \text{A}^{-1}$)	chromaticity coordinates	
					CIE _x	CIE _y
1 #	40	9.29	691.7	3.46	0.332	0.342
2 #	80	9.26	575.9	2.88	0.364	0.411

It can be seen that the luminous brightness of OLED devices which is prepared by utilizing 40 nm C60 as the refractive index matching layers to improve the extraction efficiency is higher than one which is prepared by utilizing 80 nm C60 as the refractive index matching layers. These experimental results coincided with the previous numerical transmission of multilayer (ETL/EIL/Mg : Ag/C60). The change between

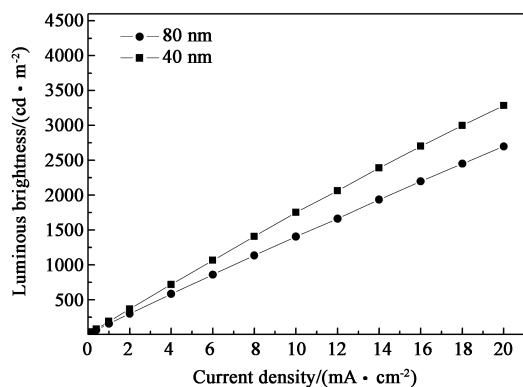


Fig.4 Relationship between the luminous brightness and different C60 thickness of refractive index matching layers

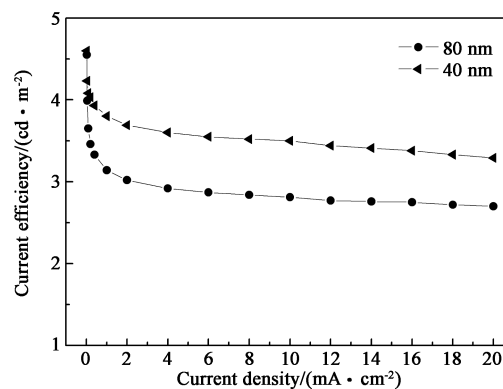


Fig.5 Relationship between the current efficiency and current density at different C60 thickness of refractive index matching layers

the current efficiency and current density at different C60 thickness of refractive index matching layers is same as before. That is to say, the OLED devices prepared by utilizing 40 nm C60 as the refractive index matching layers have higher luminous brightness and efficiency. Which also explains that the C60 refractive index matching layer with appropriate thickness on the semitransparent cathode can largely improve the

transmission of multilayer (ETL/EIL/Mg : Ag/C60), decrease the loss of light, and finally adjust the external quantum efficiency of OLED devices.

3.3 Luminescence spectrum and chromaticity coordinate shift analysis

The result of C60 thickness at 40 nm and 80 nm is shown in Fig.6. As can be seen from the chart, two OLED devices differ in luminous intensity of three primary color. When the C60 out-coupling layer of cathode makes a choice of 40 nm, the luminous intensity of three primary color is higher than the other one. From this, we can conclude that the certain thickness of C60 out-coupling layer can effectively enhance external quantum efficiency of top-emitting organic white light emitting devices.

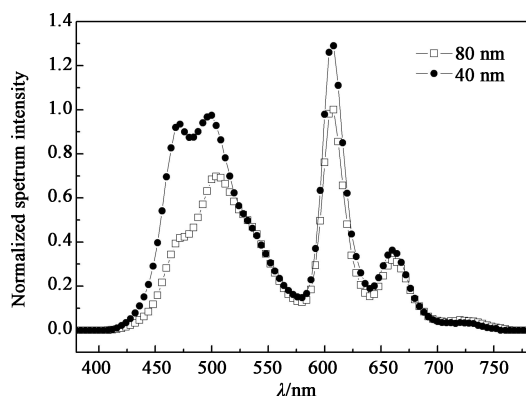


Fig. 6 Normalized electroluminescence spectra of OLED devices prepared with different C60 thickness of refractive index matching layers

The relation between the chromaticity coordinates of OLED devices prepared with refractive index matching layers of C60 which the thickness were respectively controlled at 40 nm and 80 nm and the electric current is shown in Fig.7. From the Fig. 7, we can see that the chromaticity coordinates of OLED devices give rise to shift according to the changes of electric current from 0.02~20 mA. And when the electric current increase from 0.02~20 mA, the chromaticity coordinates of OLED devices bring about blue shift, which illustrate that the ratio among the luminous intensity of three primary color

changes, the integral area of normalized electroluminescence spectra of three primary color calculated also explain this changes. It is found that when the refractive index matching layers of C60 were respectively controlled at 40 nm and 80 nm, the chromaticity coordinates of two OLED devices is (0.332, 0.342) and (0.364,0.411). The OLED devices fabricated with 40 nm C60 materials as the refractive index matching layers is mostly close to the equal energy (0.33, 0.33), but the other one is away from the equal energy (0.33, 0.33). From the above analysis, it is found that the electroluminescence spectrum and chromaticity coordinates of top-emitting OLED devices are closely related to C60 thickness, which is consistent with the numerical results of transmission spectrum of multilayer (ETL/EIL/Mg : Ag/C60) at different thickness of C60 thin films.

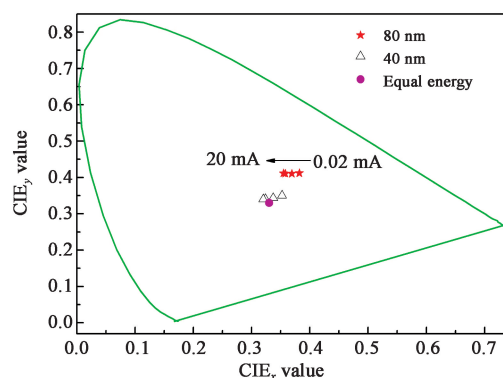


Fig. 7 Chromaticity coordinates of OLED devices prepared with different C60 thickness of refractive index matching layers

4 Conclusion

Based on relevant theory, the transmission of multilayer (ETL/EIL/Mg : Ag)/C60 thin films were numerically calculated with matlab program and the top organic white light emitting devices with common cathode configurations were fabricated. The optical and electrical properties of OLED devices prepared with different thickness of C60 refractive index matching layers were analyzed. In addition, the normalized electroluminescence spectra and chromaticity coordinates shift of OLED devices pre-

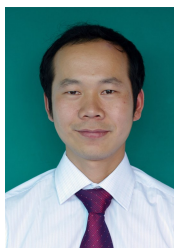
pared with refractive index matching layers of C60 which the thickness were respectively controlled at 40 nm and 80 nm were analyzed. The experimental results showed there were big difference in optical transmittance and the chromaticity coordinates of transmission spectrum of ETL/EIL/Mg : Ag/matching layers with different thickness of C60. The C60 refractive index matching layers or thickness variations are not related with the

injection, transport, recombination of carriers and produce photos. The study found that the electroluminescence spectrum and chromaticity coordinates of top-emitting OLED devices are closely related to C60 thickness, which is consistent with the numerical results of transmission spectrum of multi-layer (ETL/EIL/Mg : Ag/ C60) at different thickness of C60 thin films.

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