Research Article

Studying the Attribution of LiF in OLED by the C-V Characteristics

Chun-lin Zhang,^{1,2} Fang-cong Wang,¹ Yong Zhang,³ Hai-xia Li,⁴ and Su Liu¹

¹ Institute of Microelectronics, School of Physical Science and Technology, Lanzhou University, Lanzhou City 730000, China

² School of Mathematics, Physics and Software Engineering, Lanzhou Jiaotong University, Lanzhou University, Lanzhou 730070, China

³ Editorial Board of Journal of Lanzhou University, Lanzhou 730000, China

⁴ Institute of Modern Physics, Chinese Academy of Sciences, Lanzhou 73000, China

Correspondence should be addressed to Su Liu, liusu@lzu.edu.cn

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The organic light-emitting device (OLED) with simple structures of indium tin oxide (ITO)/tris(8-quinolinolato) aluminum (Alq₃)/LiF/Al and ITO/Alq₃/Al was fabricated to analyze the contribution of LiF in OLED. We used the C-V characteristics to investigate the contribution of LiF in OLED and found that the capacitance of the above-mentioned structures was 12.5 nF and 77.5 nF, respectively. It is shown that the LiF layer affects the property of OLED resulting in the change of the capacitance of the device.

1. Introduction

C-V Since the OLED was developed, the OLED has been considered as a promising candidate for full-color, flat panel display because of its prominent advantages, such as simplicity in fabrication and convenience in application [1]. Much effort has been made to improve the performance of the device. It is known that the performance of OLED depends heavily on the efficiency of carriers injection and their recombination, which generates molecular excitons, as well as the balance between the holes and electrons [2]. In order to achieve maximal efficiency, we hold the view that it is essential that more electrons should be injected into the emission layer.

However, since electron mobility is much lower than hole mobility, OLED has a fatal problem for applications due to its relatively low efficiency in comparison with other competitive displays. It is generally considered that the balanced carriers are desirable for high electroluminescence (EL) efficiency, low operation voltage, and high brightness. So, finding a way of increasing the number of electrons or reducing the number of holes which could reach the

cathode is considered as one of the most direct and economic solutions to improve the efficiency of the device.

So far, there have been several approaches to increase the number of injected electrons including modification of the cathode contact and electron transport layer, which has been known to improve carriers' balance and recombination [3, 4]. One of the simplest and often-used methods is to insert a buffer layer as the electron-injection layer (EIL), such as the inorganic LiF [5], CsF [6], NaCl [7], NaF [8], Al₂O₃ [9], SiO₂, and MgO, between an emitting layer (EL) and the cathode, this can improve the device efficiency and stability [10]. In contrast to the conventional view that the existence of such an extra insulating layer might increase the turn-on voltage a significant decrease in turn-on voltage is usually observed in the OLED if such a buffer layer is used. The reason lies in that effective energy barrier has been reduced because of the increased charges injection [11–13] and the presence of low work-function metal following the chemical reaction of buffer materials [14]. In fact, the low work-function metal is usually neglected when we consider the energy barrier between the metal and other materials, because its contribution can be ignored.

In this paper, the authors demonstrated the contribution of such a buffer layer which can significantly improve the device performance by increasing the number of injected electrons and reducing the number of holes which could reach the cathode.

2. Experimental Details

In our experiment, the standard OLED was fabricated and the ITO-coated glass substrates with a sheet resistance of about $30 \Omega/\text{sq}$ and the thickness of 150 nm were supplied by South Glass, Ltd. The OLED was made by following process. First, ITO-coated glasses were cleaned by using acetone, alcohol, and deionized water in an ultrasonic bath at 60°C for 20 minutes and dried by using N_2 gas with a purity of 99.99%. Second, the films of Alq_3 and LiF were sequentially grown on ITO-coated glass by thermal evaporation under high vacuum with $3 \times 10^{-3} \text{ Pa}$ at room temperature, and the growth rate of Alq_3 was 0.1 nm/s and that of LiF was 0.02 nm/s. Finally, Al metal was evaporated on Alq_3 or LiF/ Alq_3 film at the rate of 0.5 nm/s. The thickness of the films was controlled by a quartz thickness monitor.

In this research, the purity of LiF was 99.99%, and the following two structures were fabricated:

Type A: Al (110 nm)/LiF (1 nm)/ Alq_3 (65 nm)/ITO (150 nm),

type B: Al (110 nm)/ Alq_3 (65 nm)/ITO (150 nm).

Their capacitance-voltage (C-V) was measured by KEITHLEY 4200, at the same time, we measured their current density-voltage (J-V) and Luminescence-Voltage (L-V) characteristics by KEITHLEY 228A and ST-86LA spot photometer, respectively. All the measurements were done under ambient conditions without encapsulation.

3. Results and Discussion

According to the classical theory [15], the junction capacitance is

$$C = \frac{\varepsilon \cdot S}{W}. \quad (1)$$

To type A, the capacitance is

$$\begin{aligned} \frac{1}{C_A} &= \frac{1}{C_{\text{Alq}_3}} + \frac{1}{C_{\text{LiF}}} \\ \Rightarrow C_A &= \frac{C_{\text{Alq}_3} \cdot C_{\text{LiF}}}{C_{\text{Alq}_3} + C_{\text{LiF}}}. \end{aligned} \quad (2)$$

To type B, the capacitance is

$$C_B = C_{\text{Alq}_3}. \quad (3)$$

To the Alq_3 layer, the capacitance is

$$C_{\text{Alq}_3} = \frac{\varepsilon_{\text{Alq}_3} S}{W}. \quad (4)$$

FIGURE 1: The C-V characteristics of the device with the structure of ITO/ Alq_3 /LiF/Al.

FIGURE 2: The C-V characteristics of the device with the structure of ITO/ Alq_3 /Al.

To the LiF layer, the capacitance is

$$C_{\text{LiF}} = \frac{\varepsilon_{\text{LiF}} S}{W}. \quad (5)$$

According to (4) and (5), it is obviously obtained that the C_{Alq_3} is smaller than the C_{LiF} , because the thickness W of the films of Alq_3 and LiF is 65 nm and 1 nm, respectively; Alq_3 is an organic semiconducting material; LiF is an insulating material, so the dielectric constant ε of the Alq_3 is smaller than that of the LiF.

From Figures 1 and 2, we could get that the capacitance of type A and B is 12.5 nF and 77.5 nF, respectively. So there must be a reaction between the insulating layer (LiF) and the active layer (Alq_3), or we could not get the result that the C_A is smaller than the C_B . Here the capacitance of Alq_3 is much smaller

ITO	Alq ₃	Alq ₃ (F ⁻)	Alq ₃ (Li ⁺)	LiF	Al
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FIGURE 3: The inner structure of the device of ITO/Alq₃/LiF/Al.

than that of the LiF; hence we could ignore the capacitance of the LiF layer. Because the C_A is much smaller than the C_B , we could get that the $\epsilon[\text{LiF (1 nm)}/\text{Alq}_3 \text{ (65 nm)}]$ is smaller than the $\epsilon[\text{Alq}_3 \text{ (65 nm)}]$. So the number of the injected electrons in the devices with LiF layer is much more than that in the device without the LiF layer, and the electrons could be injected continually to the Alq₃ layer to protract the life of the OLED.

We could also obtain that the film of Alq₃ must be separated into three parts, and just like Figure 3 shows, the Alq₃ of the blank zone which is far from the LiF layer keeps its nature while the Alq₃ of the shadow zone has been changed. There is a reaction between the Alq₃ and the LiF here. Once the high electric field was given to the device, the LiF would be separated into Li⁺ and F⁻ and the Li⁺ would stay in the area which is close to the cathode in the shadow zone, while the F⁻ would be pushed to the area which is far from the cathode in the shadow zone. The area with Li⁺ where there must be more free carriers becomes well conductive, and the area with F⁻ where there must be less free carriers becomes well insulating for electrons. The number of injected and transported electrons which could reach the emitting zone was increased. The balance of the injected holes from the anode and the injected electrons was well kept. The holes which could reach to the cathode were reduced because the area with Li⁺ has changed into the conductive layer, and it would stop the holes to the largest extent. There were no more waste holes, and no more annihilation phenomenon occurred. Most of the excitations would be only produced in the film of Alq₃. The result was that the operation voltage and the luminance could be obviously improved.

The J - V characteristics of the two types of devices are shown in Figure 4. The current density of type B at the same driving voltage is smaller than that of type A as shown in the example that the turn-on voltage is 11 V for type A, and 9 V for type B. Figure 5 shows the luminance measured as a function of voltage for the two types of devices. The luminance of type A at 16 V (1718 cd/m²) is higher than that of type B (1250 cd/m²). The improvement in luminance and operation voltage with LiF between the Alq₃ and Al may be attributed to an enhanced balance of the holes and electrons. Electrons possessed a much lower mobility than holes in the organic materials [16]; this gives rise to an accumulation of excess holes at the ITO/Alq₃ boundary, and either increasing the number of electrons or decreasing the number of holes may help to improve the situation obviously. The presence of a LiF layer at the organic-Al interface can further reduce the barrier height for electron injection from the cathode, and it can enhance the performance of OLED.

FIGURE 4: The J - V characteristics for ITO/Alq₃/LiF/Al (squares) and ITO/Alq₃/Al (circles) devices. FIGURE 5: The L - V characteristics for ITO/Alq₃/LiF/Al (squares) and ITO/Alq₃/Al (circles) devices.

4. Conclusions

In conclusion, we have succeeded in explaining what the insulating layers such as a LiF layer contributes in the OLED by using the C - V characteristics. There is a reaction between the Alq₃ and the LiF, and the film of Alq₃ is separated into three parts: the area which is close to the cathode is full of Li⁺, so this area becomes well conductive; the area which is far from the cathode is full of F⁻, so this area becomes well insulating. It indicates that the number of injected and transported electrons to the emitting zone is increased, and the number of holes which can reach to the cathode

is reduced. Such an insulating layer with high dielectric constant results in not only such an evident increase in luminance but also the decreasing of the turn-on voltage of the device.

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