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Separately Doped Structures for Red Organic Light Emitting Diodes

Chuan-Yi Yang[1], Yu-Sheng Tsai[2], Fuh-Shyang Juang[1], Ming-Yein Lin[1], David Lin[3], Chun-Hsun Chu[4] and Yi-Tai Chiu[4]

[1]Institute of Electro-Optical and Materials Science, National Huwei University of Science and Technology
[2]Department of Electro-Optics Engineering, National Huwei University of Science and Technology
64, Wenhua Rd., Huwei, Yunlin, 632 Taiwan
Phone: 886-5-6329643 E-mail: fsjuang@seed.net.tw
[3]Windell corporation, 1F, 9, Kung-Yen 7 Rd., Industrial Zone, Taichung, 407 Taiwan
[4]Electronics Research and Service Organization, Industrial Technology Research Institute, 30, lane 31, sec. 1, Huandung Rd., Tainan Science Industrial Park, Shinshi, Tainan, 741 Taiwan

Abstract—This paper studies the separately-doped structure of organic light emitting diode (OLED) where red dopant dye DCJT was doped into the host emitting layer tris(8-hydroxy-quinoline)aluminum (Alq3) by means of ultra thin quantum well doping. The parameters in the quantum well layer, including its width, position, number and spacing between quantum wells, were changed to study their effects on electroluminescence (EL) characteristics. It is found that thin doped-layer increased the luminance efficiency. When the quantum well doping was in the vicinity of NPB/Alq3 interface, where N,N'-diphenyl-N,N'-bis(1-naphthyl)-(1,1'-biphenyl)-4,4'-diamine (NPB) is used as a hole transport layer, luminance efficiency also increased. The highest luminance efficiency reaching 4 cd/A was achieved by using double quantum-well-doped structure with optimum doping thickness and 2 nm of space between the two wells. The study also found that double quantum-well-doped structure achieved better EL intensity than single and triple quantum-well structures.

1. Introduction

The application of doping technology to the production of OLED could achieve multi-color display and enhance the luminance yield. C.W. Tang et al. proposed the effect of doping on OLED [1] [2]. In their study of doping effect in OLED, Jie Yang et al. found that doping caused the redistribution of charge in trap-charge process and the shift of electron-hole recombination, resulting in changes to the emission characteristics [3]. Use of quantum well doping could sharply increase the emission luminance of the device. The studies of Yong Qiu et al. also found that the use of multiple quantum wells could balance carrier transportation and increase luminance efficiency [4] [5].

2. Experiments

ITO glass with sheet resistance of 10 Ω/□ was used as substrate, and luminance area was set at 1 cm^2 with lithography. ITO substrate cleaned with O_2 plasma before being placed into a vacuum evaporation chamber. NPB thickness was fixed at 40 nm. Then Alq3 and DCJT were co-evaporated, where the concentration of DCJT doped in Alq3 was 0.5 wt% and each doped layer (Alq3:DCJT) was an ultra-thin film with thickness of 5-10 Å, and hence was defined as a quantum-well-doped layer. The total thickness of Alq3 layer (including DCJT) was 60 nm. Next the device was moved to another vacuum chamber for deposition of LiF and Al, where LiF is used as a buffer layer and Al is used as a metal cathode.

3. Results and Discussion

The quantum-well-doped structure of the device: ITO/NPB/(DCJT:Alq3/Alq3)$_n$/Alq3/LiF/Al, where n=1, 2 or 3. Fig. 1 shows the separately doped structure with n=2. This paper studied three different types of devices; Type I had single quantum-well-doped structure with n=1; the DCJT:Alq3 doped layer was positioned at the interface of NPB and Alq3 (d=0) with doping thickness w, which could be 5 Å or 10 Å, where d represented the distance of quantum-well-doped layer from NPB/Alq3 interface. Type II had double quantum-well-doped structure with n=2 where both wells had thickness of 5 Å; the first well was fixed at the NPB/Alq3 interface, while the space between two wells could be 1 nm, 2 nm or 5 nm. Type III had triple quantum-well-doped structure with n=3, where the first well was positioned at the NPB/Alq3 interface and the spacing between the wells was set at 2 nm.

In the study of single quantum-well-doped structure, first the doped position was set at the NPB/Alq3 interface (d=0). It is found that EL intensity of doping thickness of 5 Å was higher than that of 10 Å. As shown in Fig. 2, with the same amount of current injection, the emission luminance of device having 5 Å doped layer thickness was far better than that of 10 Å. It could be surmised that too thick the doped layer had adverse effect on luminance intensity. Therefore, doping thickness in ensuing experiments was maintained at 5 Å. If the quantum-well-doped layer was moved farther away from NPB/Alq3 interface to d=10 nm, the primary luminescence peak of the device was shifted from 600 nm to 540 nm. As shown in Fig. 3, the red luminance efficiency of DCJT-doped layer was sharply reduced, taken over by the host emitting layer Alq3. This is because in the NPB (40 nm)/Alq3 (60 nm) structure, the electron-hole recombination zone was in close proximity to the NPB/Alq3 interface (and inside the Alq3 layer). When DCJT was doped in this recombination zone, there was energy transfer from Alq3 to DCJT to emit red light; if the DCJT-doped layer was far from the electron-hole recombination zone of NPB/Alq3 interface, DCJT did not receive energy transfer from Alq3, hence producing only weak emission of red light.

The next variable to be examined is the spacing between wells. Each quantum-well-doped layer has a fixed thickness of 5 Å (w=5 Å), but the spacing between two wells was set at 1 nm, 2 nm or 5 nm. As shown, changing the space between wells in double quantum well-doped structure would affect the overall emission characteristics of the device. As shown in Fig. 4, the double quantum-well-doped structure had the highest electroluminescence intensity when the well spacing was 2 nm; According to Fig. 4 of luminance yield versus current density, the structure with 2 nm spacing achieved the best luminance efficiency at 4 cd/A.

The last variable to be examined was the effect of number of well on the emission characteristics of the device. Fig. 5 compares the EL intensity and luminance yield of single, double and triple quantum-well-doped structures under 8 V. It is found that double well structure produced the highest intensity and luminance yield, even had higher EL intensity than the triple-doped structure.

4. Conclusion

This study changed the quantum-well-doped layer thickness, position, number, and spacing between quantum wells, and found that double quantum wells doped in the vicinity of NPB/Alq3 interface with 2 nm of space between the wells had achieved optimum luminance efficiency and the highest EL intensity. It is concluded that the quantum-well-doped structure can improve the overall emission characteristics of OLED.

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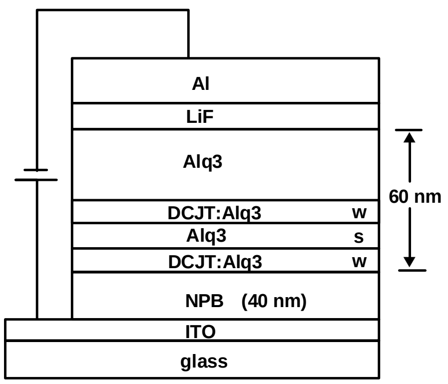

Fig. 1 Diagram of double quantum-well-doped structure (n=2).

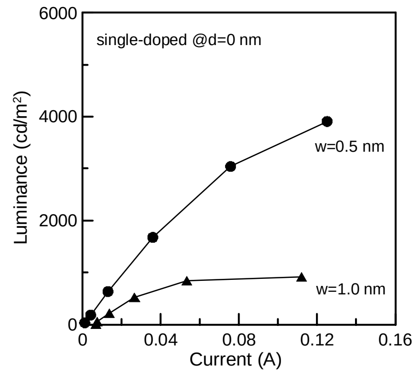

Fig. 2 Luminance versus current of single quantum-well-doped structure having different doped layer thickness (@d=0 nm).

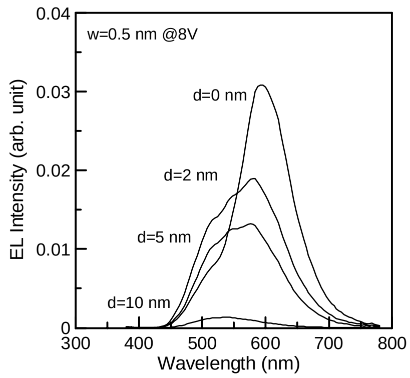

Fig. 3 EL spectra of single quantum-well-doped structure having different doped layer position (d=0, 2, 5, and 10 nm).

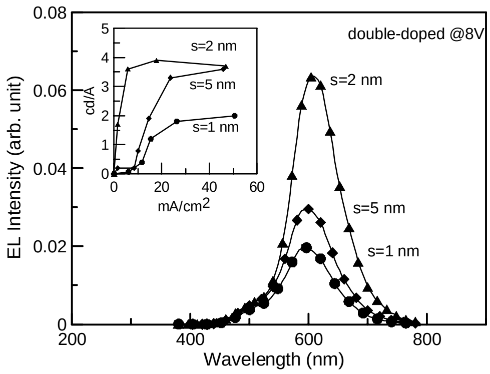

Fig. 4 Luminance yield versus current density and EL spectra of double quantum-well-doped structure with different spacing between wells (s).

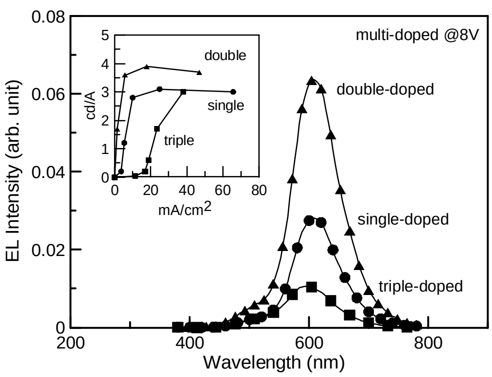

Fig. 5 Luminance yield versus current density and EL spectra of multiple quantum-well-doped structures having different number of wells (n=1, 2, or 3).