Effects of Doped-Zone Location on the CIE Value of Flexible White Organic Light Emitting Diodes

Ming-Yein Lin¹, Fuh-Shyang Juang¹, Yu-Sheng Tsai², Chuan-Yi Yang¹, Wen-Tunn Wang³ and Chai-Yuan Shen³

¹Institute of Electro-Optical and Materials Science, National Huwei University of Science and Technology

²Department of Electro-Optics Engineering, National Huwei Institute of Technology

64, Wenhua Rd., Huwei, Yunlin, 632 Taiwan

Phone: 886-5-6329643 E-mail: fsjuang@seed.net.tw

³Electronics Research and Service Organization, Industrial Technology Research Institute, 195, Chung Hsing Rd., Sec. 4, Chu Tung, Hsin Chu, 310 Taiwan

1. Introduction

The structures for white OLEDs could be of multi-layers [1-4], of microcavity [5], polymer blended [6-8], or of organic multi-quantum wells. In multi-layer structures, the white color may result from the combination of two colors (red and blue) or three colors (red, blue and green). Recently, due to their flexibility, light weight, and un-fragile issues, the flexible substrates have been used to replace the glass substrates and have become a very hot topic for researchers.

2. Experiments

The typical device consists of an ITO-coated on the 30 Ω/\Box polyethylene terephthalate (PET) substrate. N,N'-diphenyl-N,N'-bis(3-methyl-pheny)-1,1'dipheny1-4,4 'diamine (TPD) and N,N'-bis-(1-naphthyl)-N,N'- diphenyl-1,1'-biphenyl-4,4'-diamine (NPB) as a hole-transport mate-8-hydroxyquinoline rial, aluminum (Alq3) as а electron-transport green-emitting and material, 4,4'-Bis(diphenylvinyleny)-biphenyl (ADS082 of American Dye Source, Inc.) as a blue-emitting material, coumarin 6 (C6) and fluorescent dye DCJT as guest-emitting materials. The ITO-coated PET cleaned with O₂ plasma. The LiF/Al as a cathode was deposited onto the organic film by vacuum evaporation. On the flexible PET substrates four different device-structures were fabricated respectively for the white OLED study.

3. Results and Discussion

In structure A, a 2 wt% red dopant, DCJT, was fully doped in the AlQ3 layer. The schematic diagram of the energy band is shown in Fig. 1(a). The emitted spectra biased from 11-14 V are shown in Fig.2 with solid lines. The spectra contain two main peaks located at 465 nm and 645 nm, which is ascribed to the light emission from ADS082 of the blue-emission layer and that from DCJT dye doped in AlQ3 layer, respectively. At a bias lower than 12V, the peak of the 645 nm is higher than that of the 465 nm. The device exhibited red-rich color. But when the applied voltage was increased to 14V, the blue peak, 465 nm, turned stronger than the red one. The device emitted blue-rich color. Fig. 4 shows the variation of CIE coordinate values as a function of the applied voltage for different device-structures A (\bullet), B (\Box) and C (+), respectively. In this multiple-layer structure, the electron-hole recombination behavior happened near the ADS082/AlQ3 interface. And the fluorescent dye, DCJT, doped in AlQ3, has higher luminescence efficiency, compared with ADS082 emissive layer. So the red emission is stronger than the blue one at a low bias. When the applied voltage increased, the DCJT:AlQ3 emission was saturated and more electrons can thus break the barrier between AlQ3 and ADS082 to be injected into ADS082 layer. So the blue emission grew stronger than the red one at 14 V, leading to the shift of CIE coordinates.

In structure B, DCJT was doped partially in ADS082 and at the TPD/ADS082 interface. The schematic diagram of the energy band is shown in Fig. 1 (b). The emitted spectra of structure B biased from 16-18 V are shown in Fig.2 with dashed lines. It is found that the blue emission is much stronger than the red one even at high voltage. It is apparent that the DCJT dopants can not contribute to the device emission, due to the fact that recombination zone was located exactly at the TPD/ADS082 interface. From the observation of the strong blue emission in structure B, we can know that the electron-hole recombination zone exists inside the ADS082 blue emissive layer, but far away from the TPD/DCJT:ADS082 interface. As can be seen in Fig.4, the CIE coordinates of structure B shift toward the bluer region (near (0.21, 0.17)) with an increasing voltage. So the recombination zone still existed at the same position even at the high applied voltage of 18V.

In structure C, a 2 wt% red dopant, DCJT, 10 nm thick was partially doped in the middle of ADS082 and 5 nm away from the ADS082/AlQ3 interface. The schematic diagram of the energy band diagram is shown in Fig. 1(c). The device-structure C emitted a very purely white color whose spectra are shown in Fig. 3 with dashed lines and CIE coordinates in Fig. 4 (data +). The spectra contain two main peaks, blue and red, which are ascribed to the light emission from ADS082 of the blue emissive layer and that from DCJT dye doped in ADS082 layer. Greenish emission from AlQ3 partially contributed to the broader EL spectra of structure C. The three colors totally combine completely to emit a white light. The DCJT:ADS082 layer can emit red color, which indicates the right doping position at meeting the electron-hole recombination zone in the ADS082 layer. From Fig. 4, it is also observed that the CIE coordinates of structure C do not shift with different applied voltages and are almost fixed at (0,33, 0,33). This also indicates that the electron-hole recombination zone doesn't shift with different applied voltages.

In structure D, NPB was used in stead of TPD as the hole-transporting layer. A 2 wt% red dopant, DCJT, 5 nm thick was partially doped in the middle of ADS082 and 5 nm away from the NPB/ADS082 interface, and a green dopant, C6, 5 nm thick was partially doped in the middle of ADS082 and 10 nm away from the NPB/ADS082 interface. The schematic of the energy band diagram is shown in Fig. 1(d). The device-structure D emitted a white color whose spectra are shown in Fig. 3 with solid lines and CIE coordinates in Fig. 4 (data 'triangular symbol'). In this structure, blue and red light are ascribed to the emission from ADS082 and that from DCJT:ADS082, respectively. The L-V characteristics of C and D are shown in the insert of Fig. 3. The structure D can achieve highest brightness >1000 cd/m^2 and luminance yield > 4 cd/A. The brightness of structure D is 10 times higher than that of structure C.

4. Conclusion

A flexible white OLED has been successfully fabricated on the ITO-coated PET substrates. The different device structures were studied. In structure A with DCJT fully doped in AlQ3 layer, the emitted color shifted from green-rich to blue-rich with an increasing voltage. In structure B with DCJT doped in the TPD/ADS082 interface, no red emission was observed due to the fact that the doping location doesn't fit into to the recombination zone. In structure C, the DCJT doping position was set at the middle of blue emissive ADS082 layer. The combination of the blue emission from ADS082, the red emission from DCJT dye doped in ADS082 with appropriate doping location and partially greenish from AlQ3, is expected to afford a white light device. Finally, when NPB was used as hole-transport material, the brightness of device increased ten times higher than TPD's. And it was found that the electron-hole recombination zone dramatically varied with different hole transport materials.

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Fig. 1 The schematic energy band diagrams of the energy band for different device structures.



Fig. 3 EL spectra and L-V characteristics for device structures C and D.



Fig. 4 Variation of CIE coordinates with applied voltage for three different device structure.