Using Förster energy transfer for fabrication of organic light-emitting device

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Abstract. Blue fluorescent material combined with red fluorescent dye doped into tris-(8-hydroxyquinoline) aluminum (Alq) in multilayer organic light-emitting diodes(OLEDs) were investigated. Basis device architecture is indium tin oxide (ITO)/ N,N′-bis-(1-naphthyl)-N,N′-diphenyl-1,1′-biph-enyl-4,4′-diamine(NPB 20nm)/ 4, 4'-bis (2,2'-diphenyl vinyl)-1,1'-biphenyl (DPVBi 10nm) / tris-(8-hydroxyquinoline) aluminum (Alq) : 5H-benzo[ij] quinolizin-9-yl)ethenyl] -4H-pyran-4-ylidene]propane-dinitrile (DCM2 0.8% 7nm) / (Alq 13nm)/LiF (0.65nm) /Al. Exciton recombination zone is located at DPVBi and DCM2 doped into Alq layers. The Commission Internationale de1'Eclairage (CIE) coordinates of the device change from (0.4458,0.4589) at 5V to (0.3379,0.2611) at 12V that are well in the white region. Its maximum luminance was 4248 cd/m^2 at 12V, and maximum current efficiency was 7.21cd/A at 5V, respectively.

Introduction

Studies of organic light-emitting device (OLED) are continuously expanded nowadays because of its advantages such as bright, emissive, colorful devices that offer quick response time, wide operation temperature, light weight, high luminance, flexibility, and so on. Especially white OLED (WOLED) that has promising application in the fields of display and solid-state lighting [1-4]. For the applications in display as well as solid-state lighting, white light, which is usually composed of three discrete peaks in the red(R), green(G) and blue(B) regions or two complementary colors, such as blue and orange, is generally required. Among them, the multi-EML structure has advantages over other architectures in terms of efficiency and color control ability because the recombination current, singlet and triplet energy transfer and light-emitting performance of each layer can be easily controlled by thickness, and doping concentration of each EML, respectively. Light emission of different colors is generated by direct recombination of holes and electrons in emissive materials [5] and/or by energy transfer between various materials [6]. For direct recombination of carriers, an excited state (i.e. exciton) is formed by the sequential trapping of a hole and then an electron onto the emissive material. So-called energy transfer is that energy of excitons formed in a high band gap material (i.e. donor) is transferred to a luminophore with a lower band gap (i.e. acceptor) located with in the potential radius of the exciton to make the luminophore emit light. Generally, there are two path ways of energy transfer: short range Dexter transfer of triplet excitons and long range Förster energy transfer of singlet excitons. However, for WOLEDs, it is difficult to control the energy transfer between R, G and B emitters to achieve balanced white emissive under various bias conditions. As a consequence, voltage-dependent color-shifts caused by evolutions of recombination zone are often observed. It is still a relatively challenging task to keep emission color constant over a wide range of brightness levels [7–9]. After that, many works have been done for higher luminance and efficiency of WOLEDs. To achieve this purpose, it is generally agreed that besides proper selection of organic materials, efficient carrier injection from both electrodes and controlled electron-hole recombination within a well-defined zone are key factors in the performance of OLEDs. In this letter, we report a WOLED with the blue fluorescent material combined with red fluorescent dye doped into tris-(8-hydroxyquinoline) aluminum (Alq) in multilayer structure. The enhanced efficiency can be attributed to the suitable doping

concentration of red dye in the emitting layer, which leads to an increase of the Förster energy transfer. The Commission Internationale de1'Eclairage (CIE) coordinates of the device change from (0.4458, 0.4589) at 5V to (0.3379, 0.2611) at 12V that are well in the white region. Its maximum luminance was 4248 cd/m^2 at 12V, and maximum current efficiency was 7.21cd/A at 5V, respectively.

Experimental

Fig.1 shows the chemical structure of organic materials and the device structure of the OLEDs. The devices are prepared in a vacuum chamber at a pressure of 4.5*10^{-4}pa by thermal evaporation onto a cleaned indium tin oxide (ITO) coated glass substrate. The multilayer devices fabricated have the following structure: ITO/ NPB (20nm)/ Alq：DCM2 x%（7nm）/ Alq (13nm)/LiF（0.65nm）/Al，where x=0，0.5，0.8，1，called device A-D, respectively, and another device structure is ITO/ NPB(20nm)/ DPVBi(10nm)/Alq：DCM2 0.8%(7nm)/ Alq (13nm)/LiF(0.65nm)/Al called device E. The thickness of layers was controlled by quartz crystal monitor. The EL spectra and CIE coordination of the devices were measured by PR655 Spectra Scan spectrophotometer and the current–voltage–brightness characteristics were simultaneously measured by a voltage–current source (Keithley 2400). All the measurements were carried out at room temperature under ambient atmosphere.

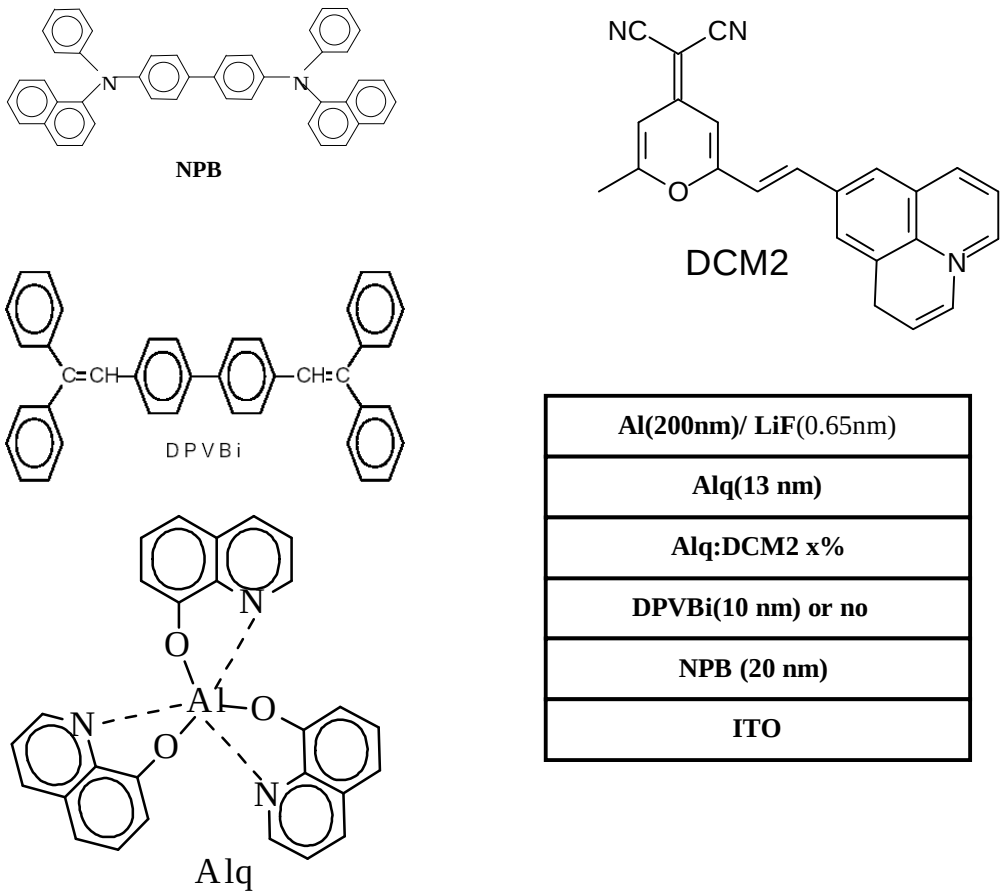


Fig. 1 The chemical structure of organic materials and the device structure of the OLEDs

Results and discussion

Fig.2 shows the Normalized EL intensity of the different devices at different voltage**.** The devices A emerging green emission with the Alq, the devices B-D shows main red emission peaks at 596 nm come from DCM2, the devices B displays minor green emission come from Alq, this observation is attributed

to the insufficiency Förster energy transfer from Alq to DCM2, but the devices C-D show red emission due to completely Förster energy transfer. The device E show two main emission peaks at 456 nm and 628 nm originating from DPVBi and DCM2, respectively.

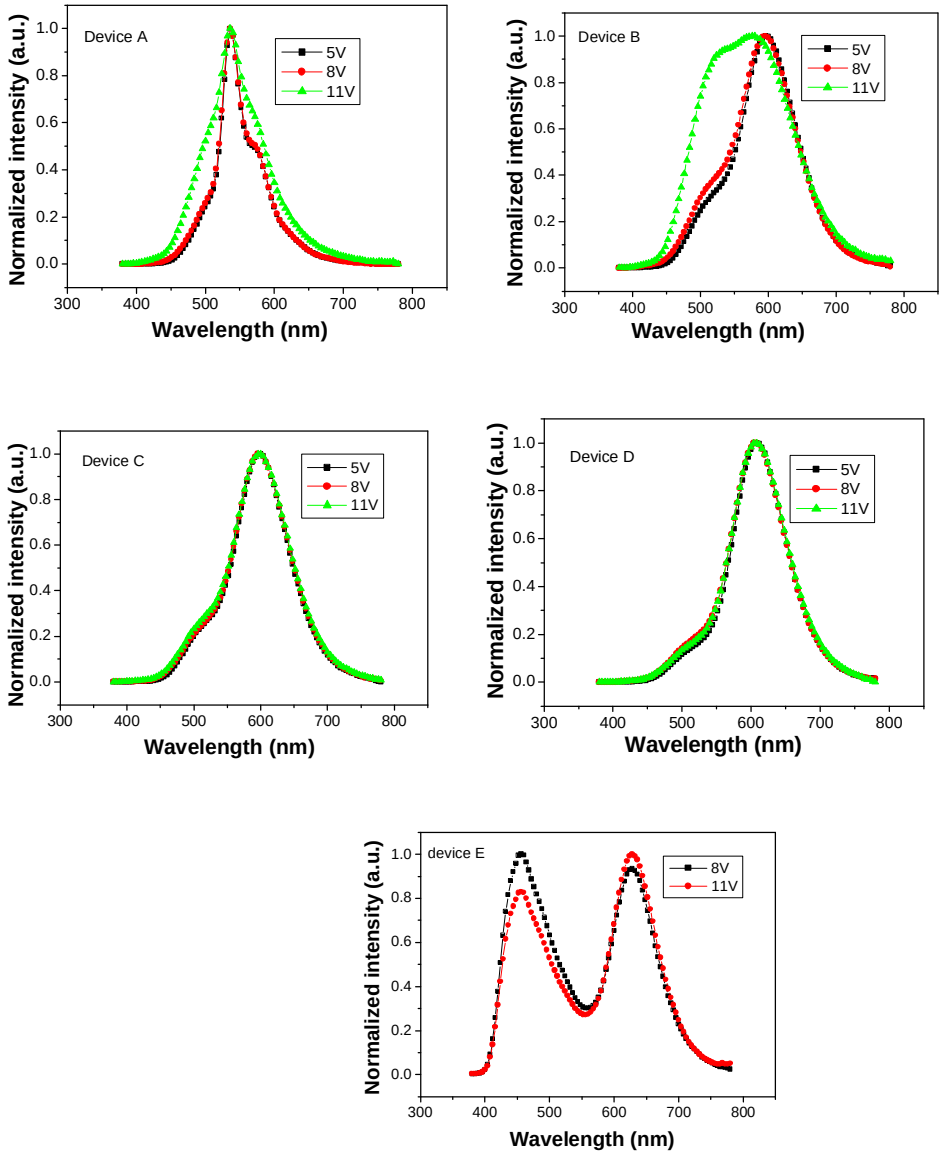
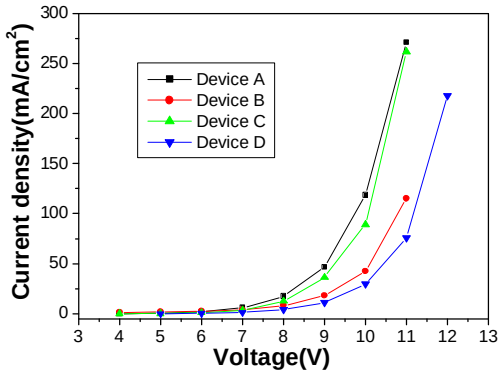


Fig. 2. Normalized EL intensity of the different devices A-E at different voltage

Fig.3 shows the current density versus voltage (J–V) characteristics of the devices. With the doping red dye to Alq, the current density for a given voltage decreases compared with no doping lay. The luminance–voltage characteristics of the devices are depicted in Fig.4, the device C has maximum luminance in same voltage. To be practical, an EL device should possess not only a high brightness but also high EL efficiency. For example, at a given voltage of 11V, the brightness of devices A-D is 12900 cd/m^2, 9604 cd/m^2, 21730 cd/m^2 and 11770 cd/m^2, respectively.



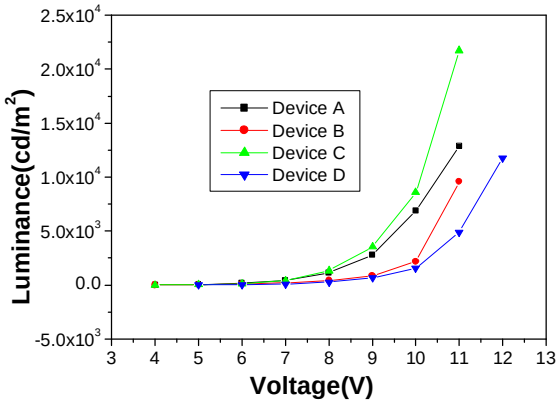


Fig 3. the current density versus voltage characteristics of the devices A-D

Fig 4. The luminance- voltage characteristics of devices A-D

Fig.5 shows the current efficiency-voltage of the devices. The maximum efficiency of devices A-D is 9.89 cd/A at 5V, 8.34 cd/A at 11V, 11.59cd/A at 5V and 7.96 cd/A at 6V, respectively. The device C exhibits the best current efficiency performance. The enhanced EL efficiency can be attributed to the perfect Förster energy transfer in the emitting layer. The current e□ciency is comparatively depends on doping concentration. The e□ect of doping concentration on the performance of organic emitting device has been invested previously. Our results indicates that for a given device structure, the proper doping concentration can enhances the performance of organic emitting device.

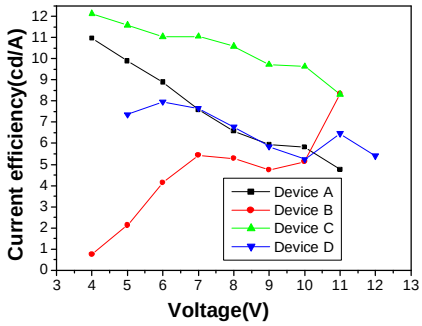


Fig 5. The current efficiency- voltage characteristics of devices A

Fig. 6 shows the optical and electronic characteristics of devices E, we can see that device E is white emit, the luminance and current efficiency were 4248 cd/m^2 at 12V and 7.21cd/A at 5V, and device has the CIE coordinates change from (0.4458, 0.4589) at 5V to (0.3379, 0.2611) at 12V that are well in the white region.

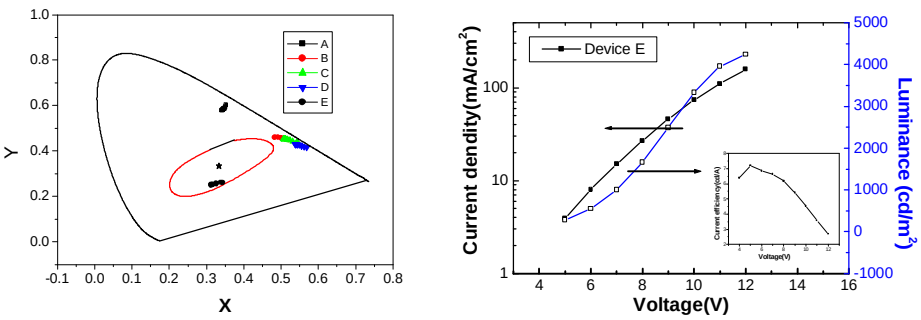


Fig6. The optical and electronic characteristics of devices E

Summary

We have fabricated e□cient multilayer devices with blue fluorescent material combined with red fluorescent dye doped into tris-(8-hydroxyquinoline) aluminum (Alq). As the emissive layer possess Förster energy transfer from Alq3 to DCM2 layer, when the doping concentration of DCM2 is 0.8%, the energy transfer is perfect. Based on above, the WOLED with blue fluorescent material combined with red fluorescent dye doped into Alq were fabricated. The Commission Internationale de1'Eclairage (CIE) coordinates of the device change from (0.4458, 0.4589) at 5V to (0.3379,0.2611) at 12V that are well in the white region. Its maximum luminance was 4248 cd/m^2 at 12V, and maximum current efficiency was 7.21cd/A at 5V, respectively.

Acknowledgements

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