

White-light-emitting Organic Electroluminescent Device Based On Incomplete Energy Transfer

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Abstract

In order to realize full color display, two approaches were used. The first method is the patterning of red, green, and blue emitters using a selective deposition. Another approach is based on a white-emitting diode, from which the three primary colors could be obtained by micro-patterned color filters. White-light-emitting organic light emitting devices (OLEDs) are attracting much attention recently due to potential applications such as backlights in liquid crystal displays (LCDs) or other illumination purposes. In order for the white OLEDs to be used as backlights in LCDs, the light emission should be bright and have Commission Internationale d'Eclairage (CIE) chromaticity coordinates of (0.33, 0.33). For obtaining white emission from OLEDs, different colors should be mixed with proper balances even though there are a few different methods for mixing colors. In this study, we will report a white organic electroluminescent device based on an incomplete energy transfer. In which the blue and green emission come from the same layer via incomplete energy transfer.

1. Introduction

Wide viewing angle, fast response, low power consumption, and the possibility of wide application has spurred interest in organic light emitting diodes (OLEDs) [1-3]. Since an organic light emitting was reported first by Tang and Vanslyke in 1987 [4], it has become an active field of research [5-7]. Several studies have been reported on white organic electro luminescent (EL) devices [1-8].

Two methods to modify the spectral characteristics of an OLED in order to achieve white

emission have been demonstrated [9-11]. First, doping the emission layer with a luminescent dye as a dopant can result in energy transfer from the host to the dopant or carrier trapping at the dopant site. This energy transfer is always incomplete and the incomplete energy transfer can then result in light emission from both the host and the dopant. This technique has been used to obtain white light emission from small-molecule-based multi-layer devices comprising two or three different layers, each emitting one color or a combination of three primary colors. Second, sandwiching a layer that preferentially blocks one type of carrier between the hole-transporting layers (HTL) and electron-transporting layers (ETL) can control the spatial location of the exciton recombination zone in order to achieve the white emission via direct color mixing [12]. It has been demonstrated to be possible to mix the different colors to generate white emission via controlling the thickness of the blocking layers, because it could change the spatial distribution of carriers across the blocking layers. Using three different color-emitting layers for the white emission is somewhat straightforward even though the structure should be more complicated. A pioneering work for obtaining the white emission has been first published by Kido *et al.* [7]. Recently, an improved method for the white-light emission was reported by Deshpande *et al.* [8]. They concluded that energy transfer occurs in a sequential manner between species in different layers across the thin hole blocking layer, so called, interlayer sequential energy transfer. In the studies using three different color emitting layers, the emitting color was tuned to white by controlling both the thickness of the blocking layer and the concentration of dopant. Therefore, the structure should be considered to not only use the carrier

blocking layer, but also the incompleteness of energy transfer between the host and dopant. But, using the blocking layer has a drawback that it blocks the movement of carrier to reduce the power efficiency of the device.

Three types of multi-layer white light-emitting devices were fabricated and tested, which are two-color and three-color devices with blocking layers, and devices without a blocking layer. The first two types use blocking layers to control a spatial distribution of carriers across the blocking layers and the third controls the spatial distribution of excitons by controlling the thickness of emission layer instead of using a blocking layer.

In this study, we will report a white organic electroluminescent device based on an incomplete energy transfer. In which the blue and green emission come from the same layer via incomplete energy transfer. For this experiment, two-emission layer was used; first layer emits two colors both blue and green. Second layer emits red color. The materials used in this experiment are 4,4'-bis(2,2-diphenyl-ethen-1-yl)-diphenyl (DPVBi) as a blue emitting material and a blue host, 3-(2-Benzothiazolyl)-7-(diethylamino)coumarin (Coumarin6) as a green emitting dopant and tris-(8-hydroxy-chinolinato)-aluminum (Alq_3) as a red host, 4-(dicyanomethylene)-2-*t*-butyl-6(1,1,7,7-tetramethyljulolidyl-9-enyl)-4*H*-pyran (DCJTB) as a red dopant.

2. Experimental

A glass substrate pre-coated with an ITO thin film with a sheet resistance of $10 \Omega/\square$ was cleaned by wet cleaning method and photo-lithographically patterned to form the transparent anode. The wet cleaning method included sonicfication by de-ionized (DI) water, degreasing by flushing in warm TCE, rinsing in acetone and methanol, and finally rinsing in DI water. On top of the anode a buffer layer of phthalocyanine copper complex (CuPc) was deposited by vacuum sublimation in order to enhance the hole injection from the anode. We used 4,4'-bis[N-(1-naphthyl)-N-phenyl-amino]biphenyl (α -NPD). We used 4,4'-bis(2,2-diphenyl-ethen-1-yl)-diphenyl (DPVBi) as a blue emitting material and a blue host, 3-(2-Benzothiazolyl)-7-(diethylamino)coumarin (Coumarin6) as a green emitting dopant and tris-(8-hydroxy-chinolinato)-aluminum (Alq_3) as a red host, 4-(dicyanomethylene)-2-*t*-butyl-6(1,1,7,7-

tetramethyljulolidyl-9-enyl)-4*H*-pyran (DCJTB) as a red dopant. A reason why we select Coumarin6-doped DPVBi and DCJTB-doped Alq_3 as emissive materials is that direct mixing of the three colors emitted from those materials could produce white emission at a certain balance. According to the concentration of dopants and thickness of the emitting layer, the spatial location of exciton recombination zone could change, and the color emitted from the OLEDs is subjected to change as the result. We controlled the concentration of Coumarin6 to emitting two colors in the one layer by incomplete energy transfer. As an ETL, Alq_3 was used on top of the emissive layers. All the organic layers were thermally deposited with an approximate growth rate of $1\text{-}2\text{\AA}/\text{s}$. For a cathode electrical contact, Al:Li alloy was finally capped over the organic layers which are thermally sublimated in a vacuum less than 10^{-6} torr. Current-voltage characteristics and luminescence intensity were measured with a Kethley 236 measure unit and a silicon photodiode calibrated with a luminance meter (Minolta CS-100). And electroluminescent spectra were measured with a fiber optic spectrometer (S2000). Current-voltage characteristics, luminance intensity and spectra were measured at the same time.

3. Results and discussion

The organic light-emitting-device (OLED) structures studied in this work are shown in Fig. 1 schematically. Fig.1 (a), (b), (c) and (d) show the structure I, II, III and IV. Structure I is the middle path of making white-light-emitting device. It was made for shows the incomplete energy transfer by green and blue emission at same time. In this structure, Concentration of the dopant was controlled by 0, 2 and 5wt%. Structure II, III, and IV is white-light-emitting devices fabricated by inserting of red-emission layer addition to Structure I. These structures have same structure except of changes of thickness of emission layer.

Fig. 2 shows the spectrums of each fabricated devices. Structure I was fabricated with controlling of the dopant concentration as 0, 2, and 5 wt%. As the figure shown, in case of making device without dopant, two peak was found. The peak at 430nm show as the emission of DPVBi used as HTL. In case of concentration of dopant was 2wt%, the device has the broad spectrum with two peak at 490nm in the blue region and 505nm in the green region. The

reason of both emission of host and dopant is the incomplete energy transfer to the dopant. Structure II, III shows another peak by the inserting of the red emission layer. It shows that white-light-emitting by the direct mixing of the blue and green color emission caused by incomplete-energy-transfer and the red color emission of the red emission layer. Structure IV was fabricated with thicker red-color-emission layer than blue-color-emission layer to increase of the intensity of the red color. Color balance was controlled by thickness of each emission layer

Fig. 3 shows the HOMO-LUMO energy level of the fabricated devices. Incomplete-energy-transfer appeared in the blue emission layer composed of DPVBi and Coumarine6. Energy of the host was transferred to dopant by energy gap. But, in case the concentration of the dopant was too low to accept the whole energy of the host, both host and dopant emission same time.

Fig. 4 (a) shows the changes caused by controlling of the concentration of dopant on the CIE color coordinate. As the picture shown, when the concentration of dopant was controlled, the resulting color emission could be changed to middle region of blue of DPVBi and green of Coumarine6. Fig. 4 (b), (c), and (d) shows the CIE coordinate of the structure II, III and IV. As the conclusion, we obtained the CIE coordinate of (0.32, 0.35) in the structure at 8V.

4. Conclusion

In this experiment, whit-light-emitting organic electroluminescent device was fabricated by controlling of the dopant-concentration. The incomplete-energy transfer was caused very low dopant concentration (2wt% in this paper) of the dopant than host. And, we achieved emission of host and dopant at the same time by incomplete energy transfer. We could fabricate the device that emits three color at the two emission layer. By the use of incomplete-energy-transfer method, We obtained the CIE coordinate of (0.32, 0.35) in the structure at 8V

5. Acknowledgements

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6. References

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	thickness
Cathode(Al:Li)	100nm
ETL(Alq_3)	25nm
EML(DPVBi : Coumarin6)	20nm
HTL(α - NPD)	25nm
CuPc	15nm
Anode(ITO substrate)	

(a)

	thickness
Cathode(Al:Li)	100nm
ETL(Alq_3)	25nm
EML(DPVBi : Coumarin6)	20nm
HTL(α - NPD)	25nm
CuPc	15nm
Anode(ITO substrate)	

(b)

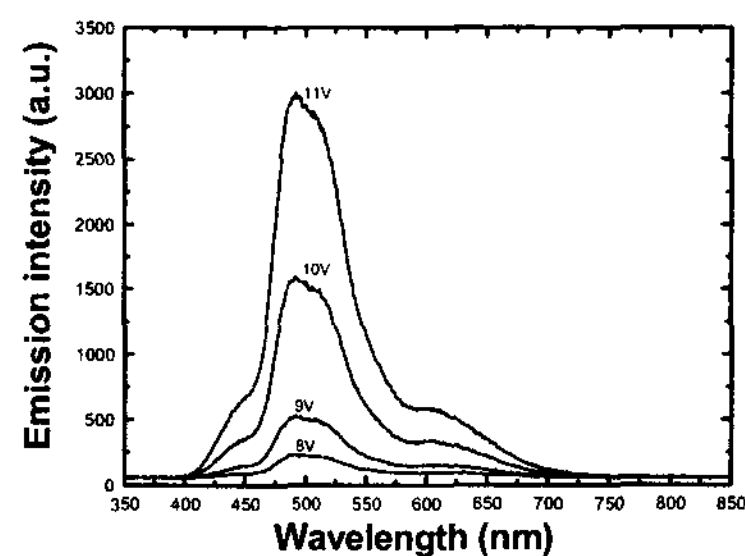
	thickness
Cathode(Al:Li)	100nm
ETL(Alq_3)	25nm
EML(DPVBi : Coumarin6)	20nm
HTL(α - NPD)	25nm
CuPc	15nm
Anode(ITO substrate)	

(c)

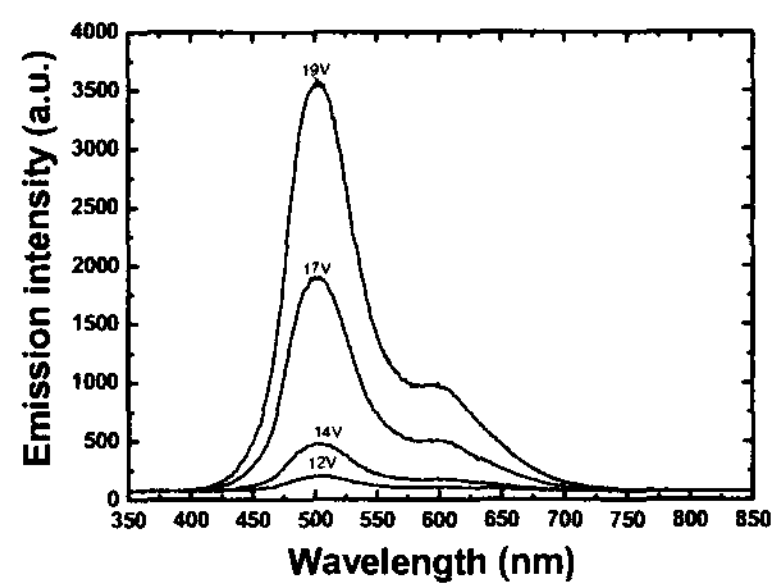
	thickness
Cathode(Al:Li)	100nm
ETL(Alq_3)	25nm
EML(DPVBi : Coumarin6)	20nm
HTL(α - NPD)	25nm
CuPc	15nm
Anode(ITO substrate)	

(d)

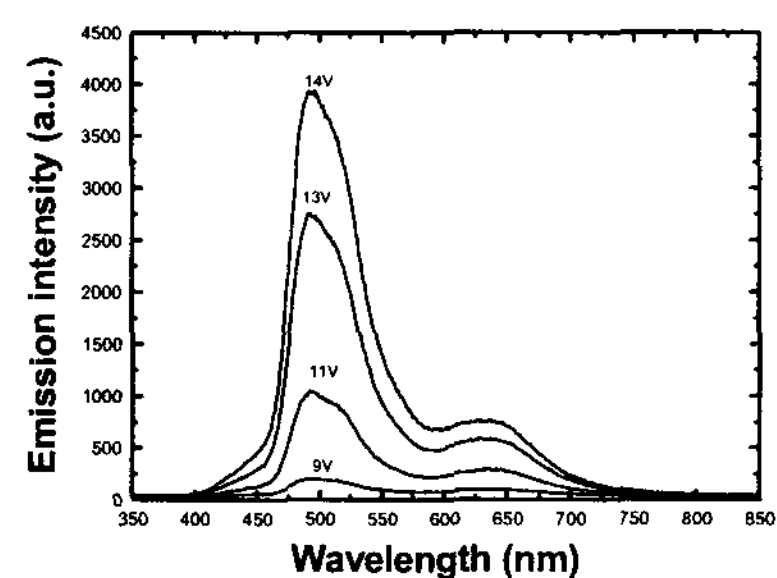
Fig. 1. The schematic cross section of fabricated OLED structure; (a) : structure (I), (b) : structure (II), (c) : structure (III), (d) : structure (IV)



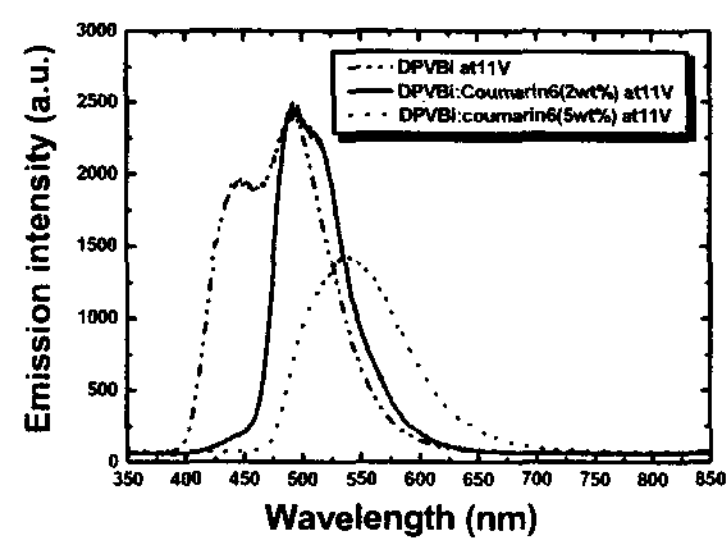
(b)



(c)



(d)



(a)

Fig. 2. EL emission spectra with applied voltage; (a) : structure (I), (b) : structure (II), (c) : structure (III), (d) : structure (IV)

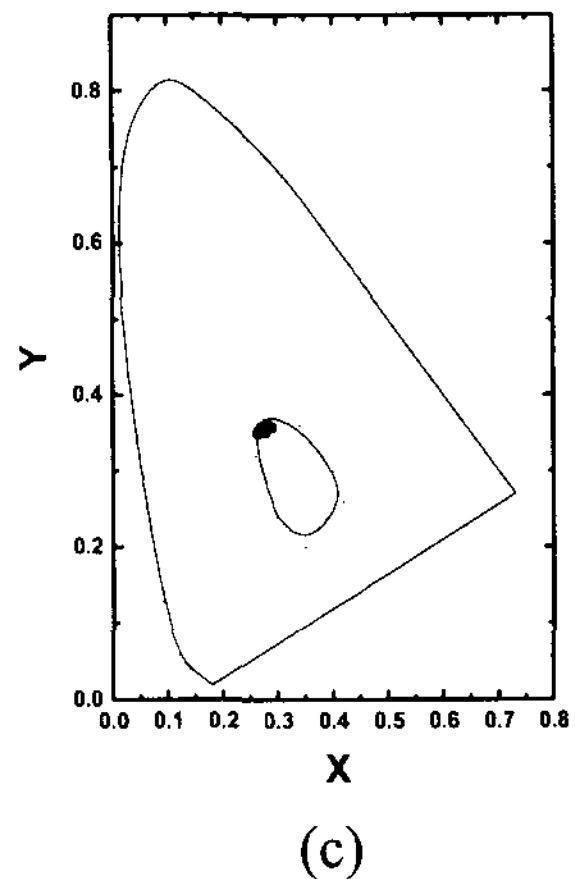
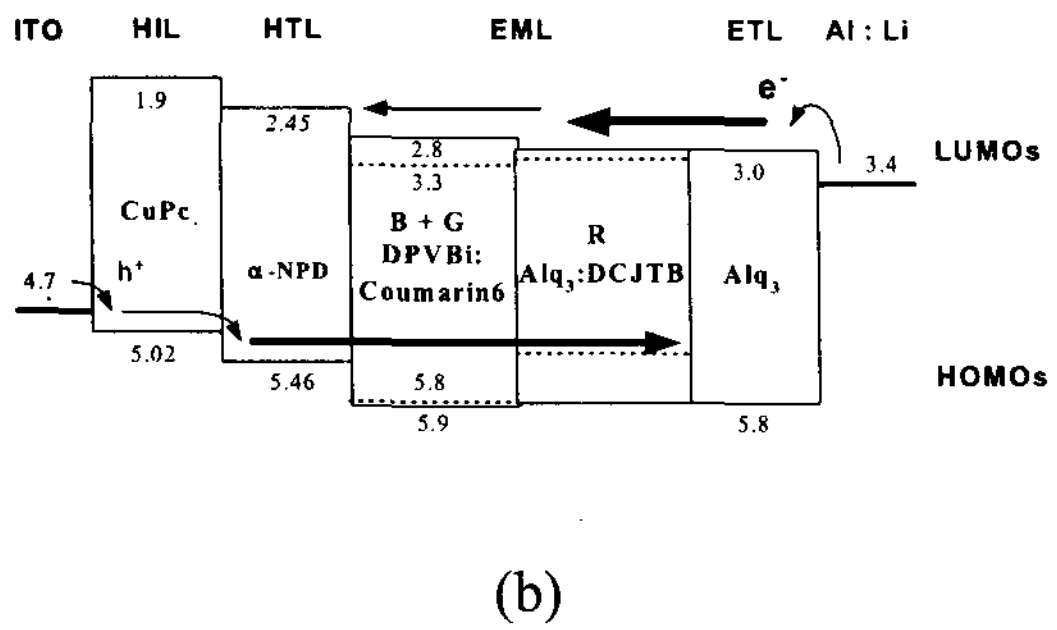
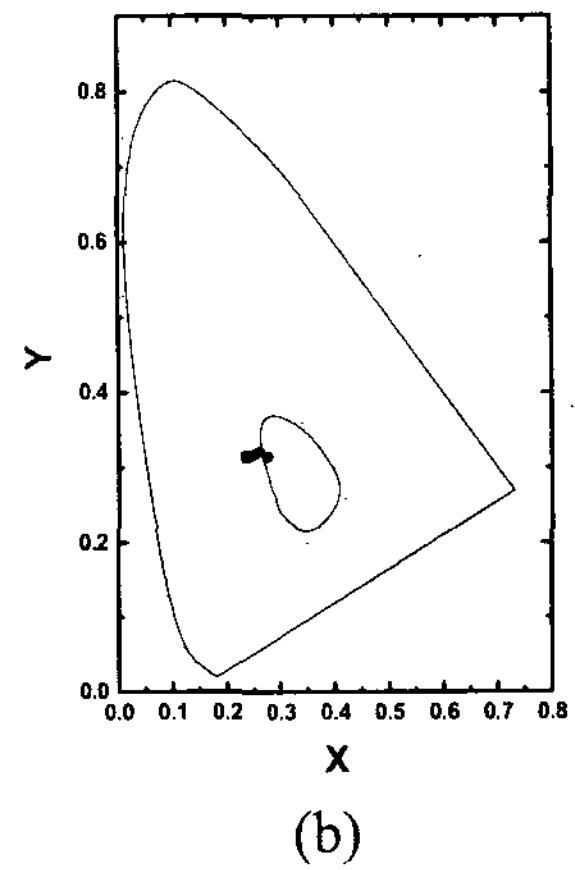
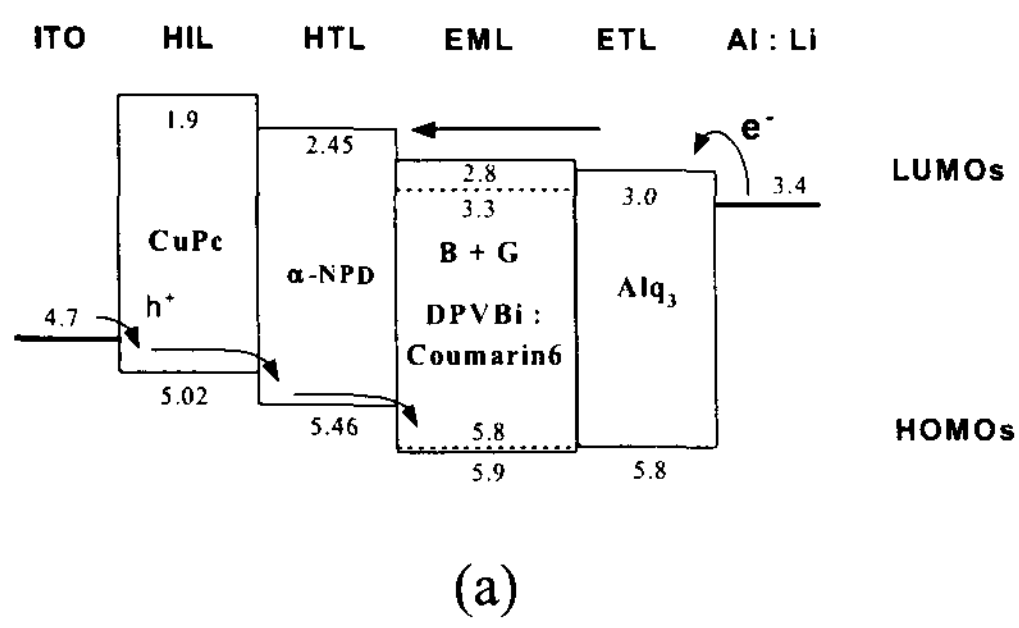


Fig. 3. The estimated energy diagrams; (a) : structure (I), (b) : structure (II), (III), and (IV)

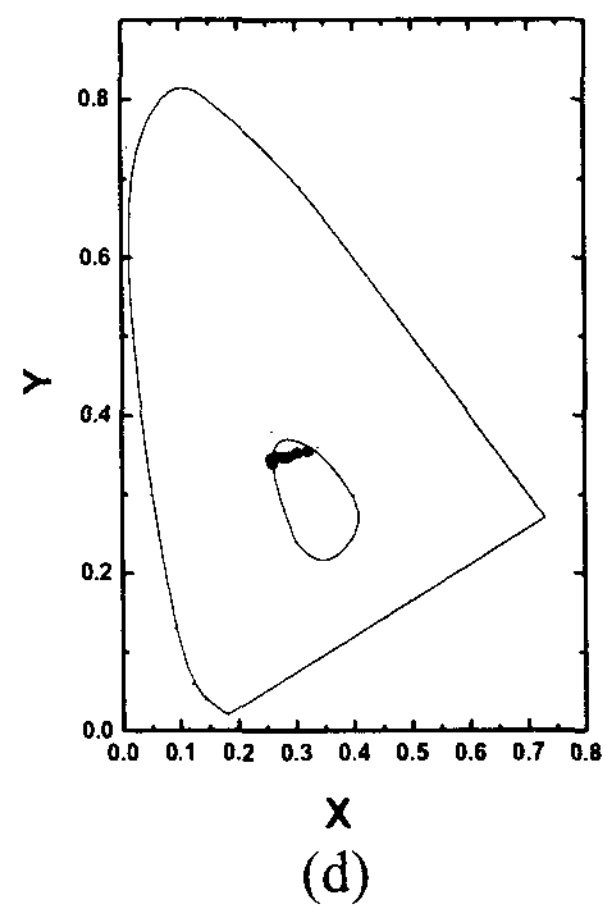
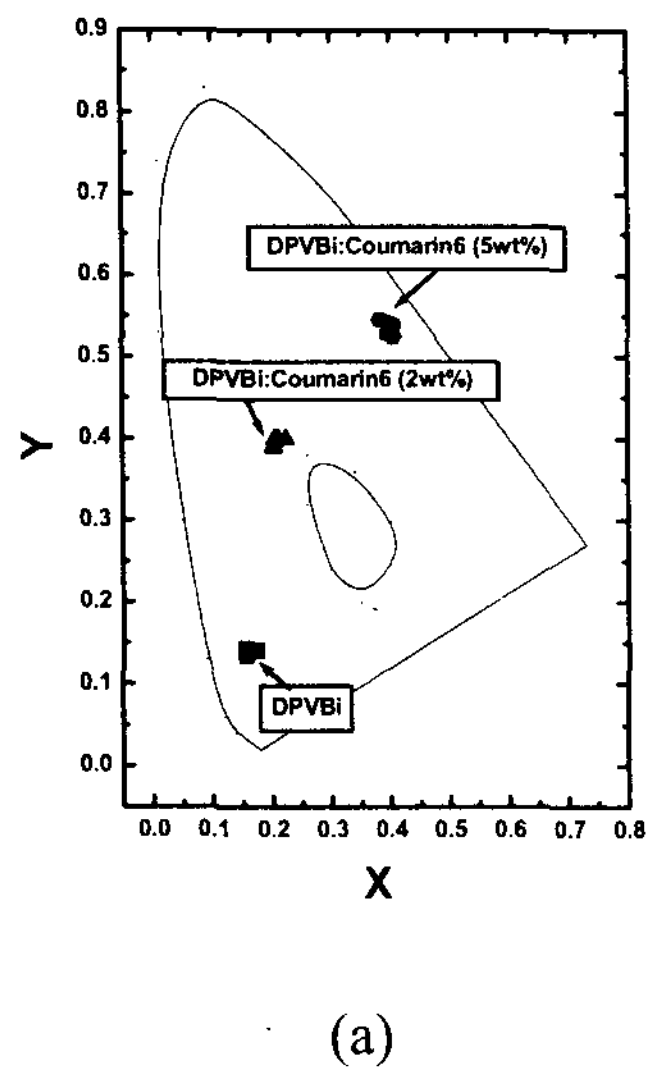


Fig. 4. The CIE chromaticity coordinate as the applied voltage changes; (a) : structure (I), (b) : structure (II), (c) : structure (III), (d) : structure (IV)