Chapter 5

Experimental Results

5.1 Overview

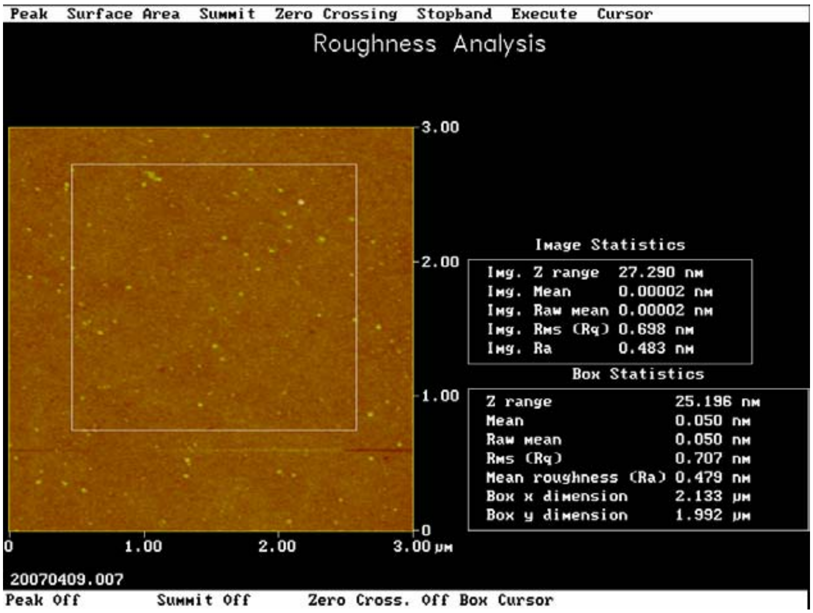
To demonstrate the emi-flective display, the proposed structure of the device integrating top emission OLED and R-LCD is fabricated. Measurement results can be categorized into surface morphology, electrical characteristics and optical performance.

5.2 Surface Morphology

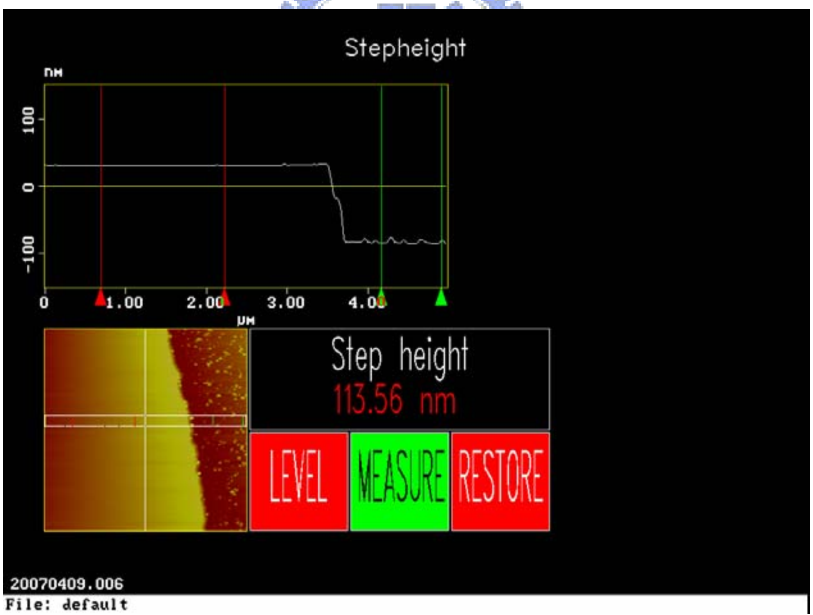
The surface morphology, such as thickness, roughness, is examined by AFM and SEM. The definition of Rq and Ra in the roughness is the root mean square average and the arithmetic average of the absolute values of the roughness profile ordinates respectively.

5.2.1 ITO Substrate

The ITO substrate used as the anode of top emission OLED requires the roughness of less than 2nm to prevent failure of top emission OLED. In addition, the thickness of ITO layer is also examined by AFM. As shown in Fig. 5.1, the roughness of ITO substrate is of less than 2nm to assure the operation of top emission OLED.



(a)

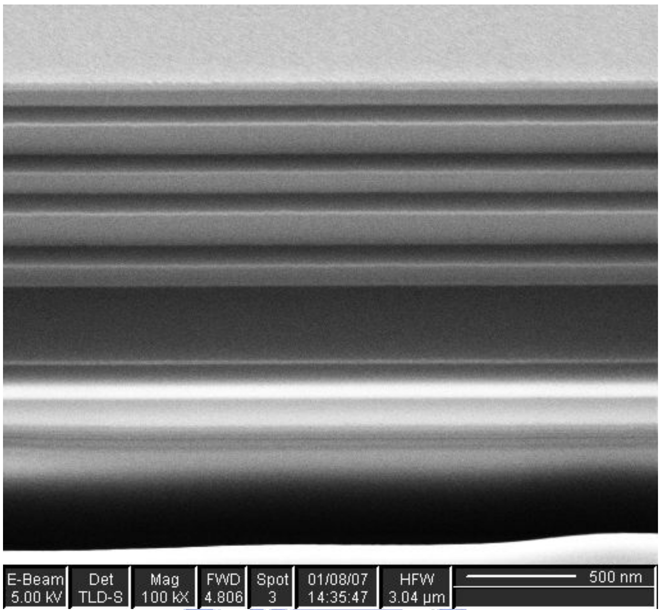


(b)

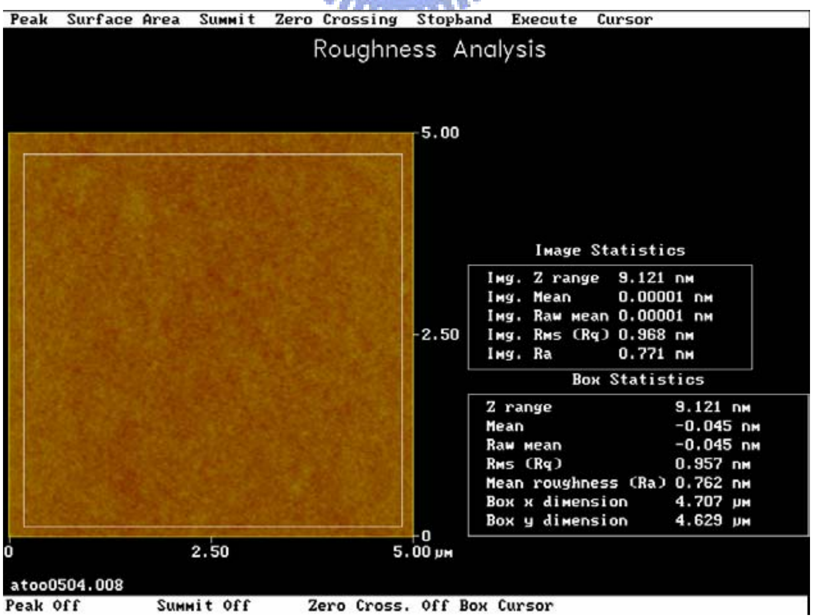
Fig. 5.1 (a) The roughness and (b) the thickness of ITO substrate

5.2.2 Passivation Layer

The thin film encapsulation is completed by depositing SiO_2 / MADN / SiO_xN_y sequentially. As shown in Fig. 5.3, the total thickness is of less than 2μm, and the roughness is of less than 1nm.



(a)



(b)

Fig. 5.2 (a) The SEM photograph and (b) the roughness of thin film encapsulation

5.2.3 Alignment Layer

The conventional liquid crystal process adopts polyimide as the material of alignment layer. By modulating the rotating speed, the thickness of polyimide is determined. The recipe of spinning coater is listed in Table 5.1, and the thickness of polyimide is shown in Fig. 5.2. In addition, the pretilt angle of the alignment process measured by crystal rotation method is listed in Table 5.2.

Table 5.1 Experimental parameters of spinning coating

Sample Size： 4cm X 4cm		
	Speed (rpm)	Time (s)
First Stage	500	20
Second Stage	5000	40

Table 5.2 The pretilt angle of the alignment layer

	Angle (degree)
Sample1	8.37
Sample2	8.79
Sample3	9.32
Average	8.83

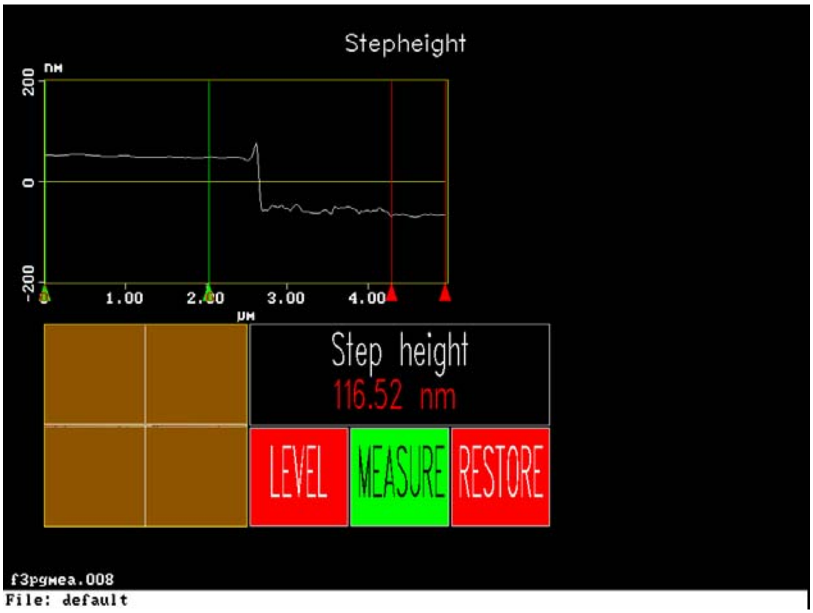


Fig. 5.3 The thickness of alignment layer

5.3 Electrical Characteristics

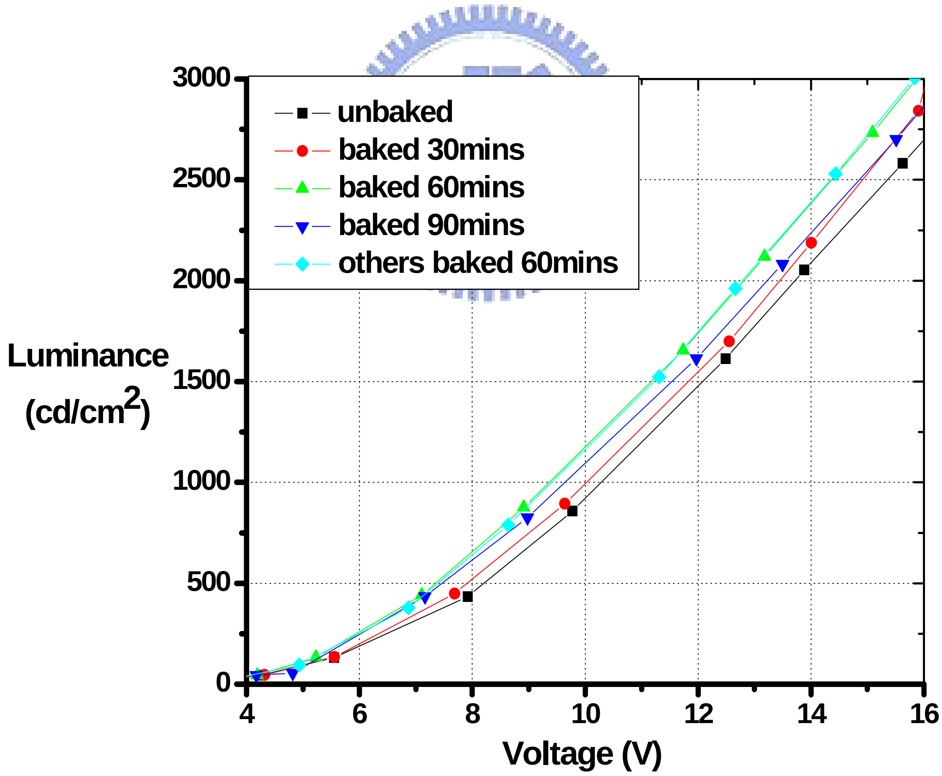
The electrical characteristics and optical performance were measured by PR-650. With the aid of the software LabView, the measurement results, such as operating voltage, luminance, efficiency, and lifetime, can be extracted in the condition of constant current.

5.3.1 Top Emission OLED

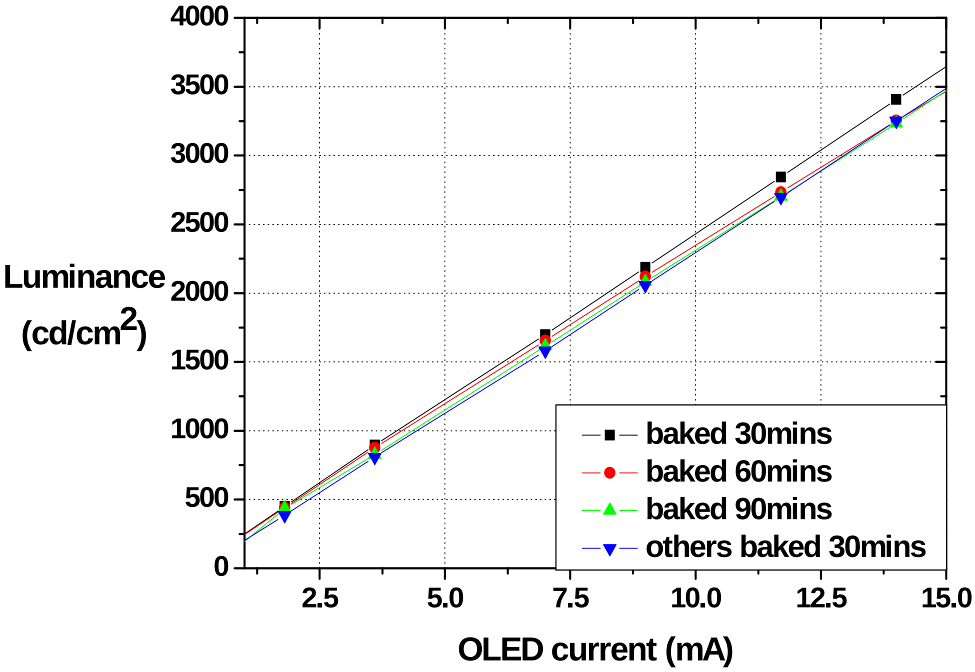
Since the alignment layer process is a high temperature one, the electrical characteristics of top emission OLED caused by the process deviates from the standard one. From the results shown in Table 5.3, the operation voltage with the approximate luminance at the same pixel varies from 9.77 volt to 8.97 volt at a current density of 48.01mA/cm^2. Moreover, the inhomogeneous heating aggravates the deviation of the electrical characteristics. As shown in Fig 5.4, operation current shows high dependence upon the luminance of top emission OLED regardless of high temperature process. Therefore, the design of the pixel circuit for emi-flective display adopts applying constant current rather than constant voltage.

Table 5.3 The deviation of operating voltage of top emission OLED

Current Density (24.00 mA/cm^2)			Current Density (48.01 mA/cm^2)			Current Density (93.34 mA/cm^2)		
	Voltage	Luminance		Voltage	Luminance		Voltage	Luminance
0 min	7.92	433.15	0 min	9.77	857.69	0 min	12.48	1613.07
30 mins	7.68	449.30	30 mins	9.64	896.38	30 mins	12.55	1698.46
60 mins	7.10	441.23	60 mins	8.91	876.92	60 mins	11.73	1654.61
90 mins	7.16	435.84	90 mins	8.97	825.38	90 mins	11.96	1614.61



(a)



(b)

Fig. 5.4 The electrical characteristics with the relationship between

(a) luminance and voltage and one between(b) luminance and current

5.3.2 The Stability of the Operation

The stability of the operation of the emiflective display is evaluated by applying constant current. The response curve of the normalized luminance is shown in Fig. 5.12. The lifetime of the emiflective display is about 100hr according to linear fit. The issue of lifetime can be overcome by the new encapsulation technology.

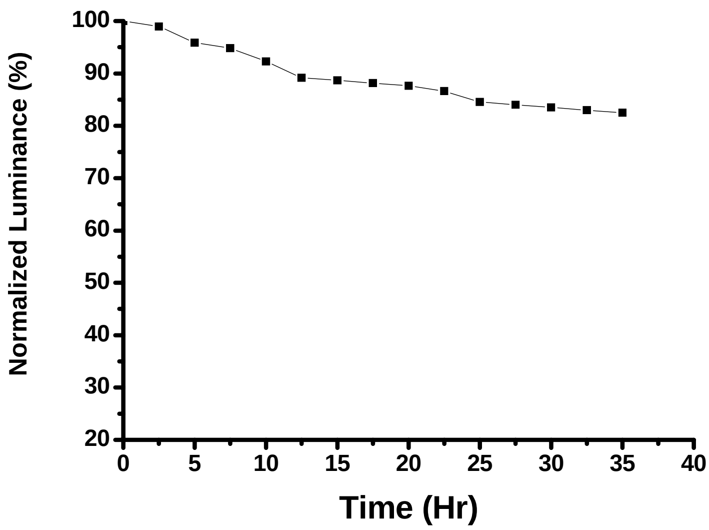


Fig. 5.5 The lifetime of the emiflective display

5.4 Optical Performance

The optical performance of the emi-flective display, such as contrast ratio, viewing angel and visual appearance, will be presented in the following sections.

5.4.1 The Ambience Contrast Ratio

The contrast ratio of the emi-flective display is measured in different operation modes. Due to the surface reflection of the emi-flective display, the washout effect is still observed and reduces the contrast ratio with the ambience. The light intensity that conoscope can provide is 20 ~ 1200 cd/cm2. A decrescent trend of the contrast ratio as the ambience luminance increases is observed in Fig. 5.5. The contrast ratio drops substantially from 1531.82 to 3.21. This is so called the washout effect which makes the OLED device illegible in bright ambience. With the aid of the component of segment recorder in the ConoScope, the surface reflectance can be eliminated significantly. The contrast ratio relieved of the washout effect decreases from 19255.7 to 301.77.

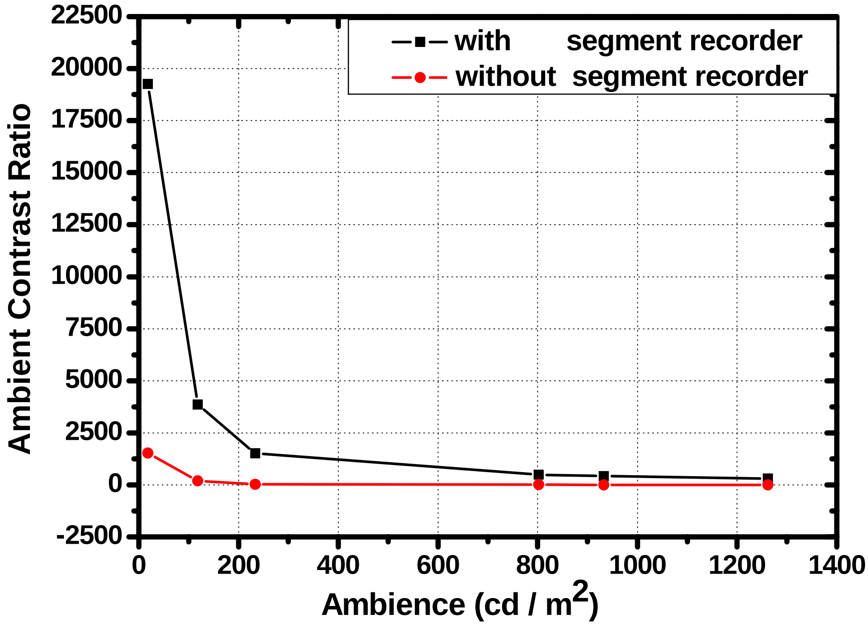


Fig. 5.6 The ambience contrast ratio of the emission mode

The contrast ratio of the reflective mode is also obtained in the ambience contrast ratio experiment. The configurations of the measured structures are shown in Fig. 5.6. As shown in Fig. 5.7, the contrast ratio on the area of the cathode of the top emission OLED with one circular polarizer is about 1.39. The main reason is that the cell gap of the photospacer, 5 μm, is too large for the emi-flective display. The function of R-LCD is a quarter waveplate for one circular polarizer, but the value of Δnd of 900nm provides an excess of phase retardation. Due to an excess of phase retardation, the dark and bright states can not be observed easily. On the other hand, the contrast ratio with two cross linear polarizers, about 3.5, is measured on the area without emissive layer and the cathode beneath it. The enhancement of the contrast ratio results from that the device with two cross linear polarizers is the conventional TN-90° LCD.

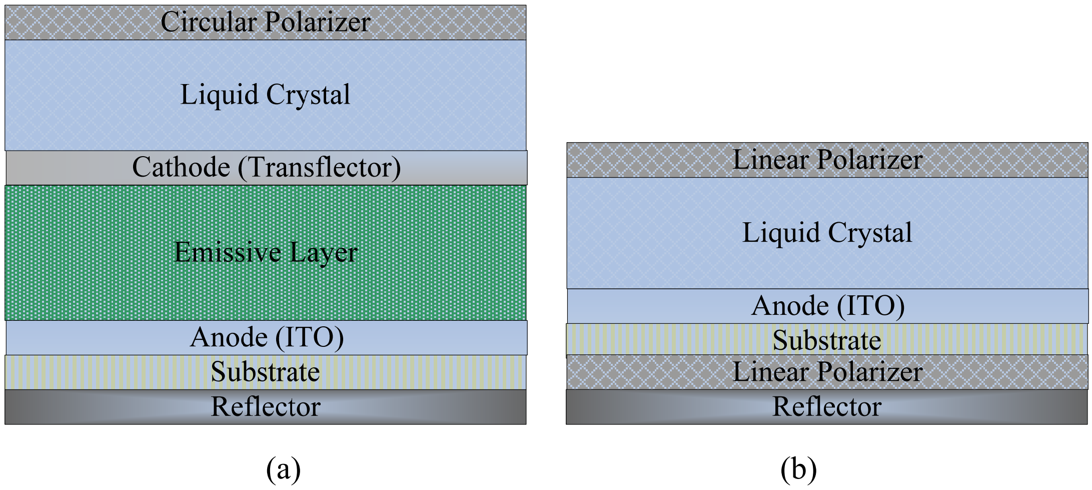


Fig. 5.7 The configurations of the measurements with (a) one circular polarizer and (b) two cross linear polarizers

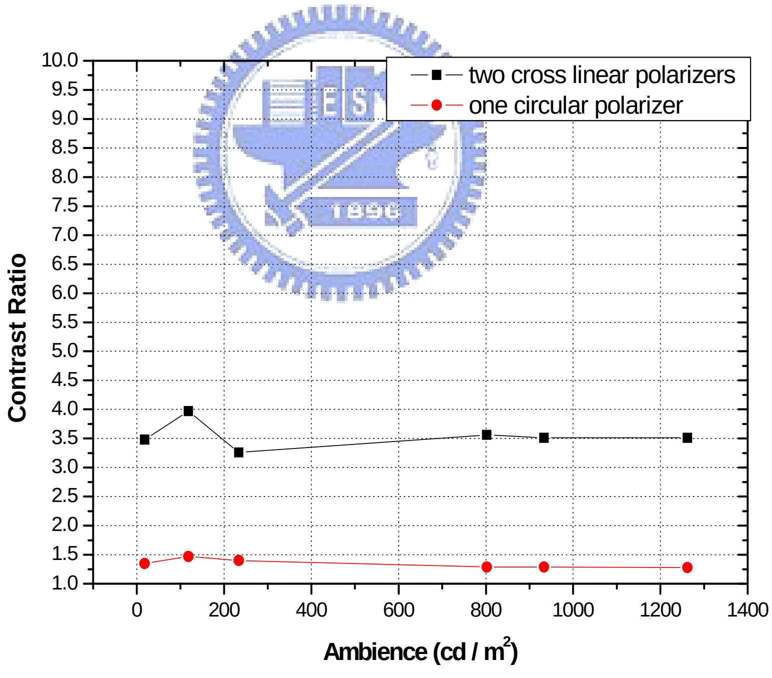
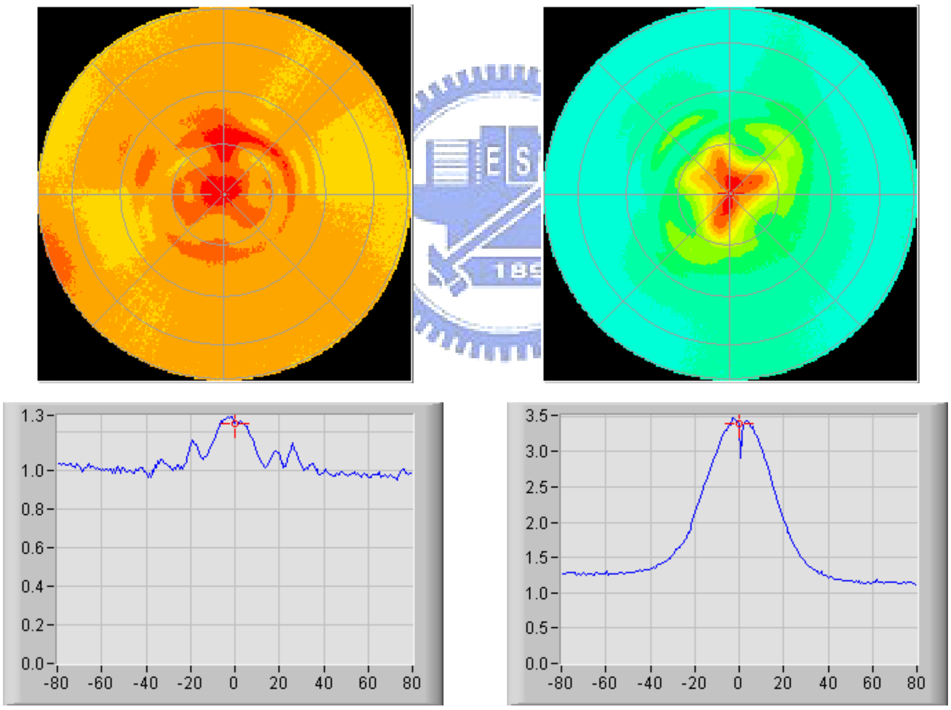


Fig. 5.8 The ambience contrast ratio of the reflective mode

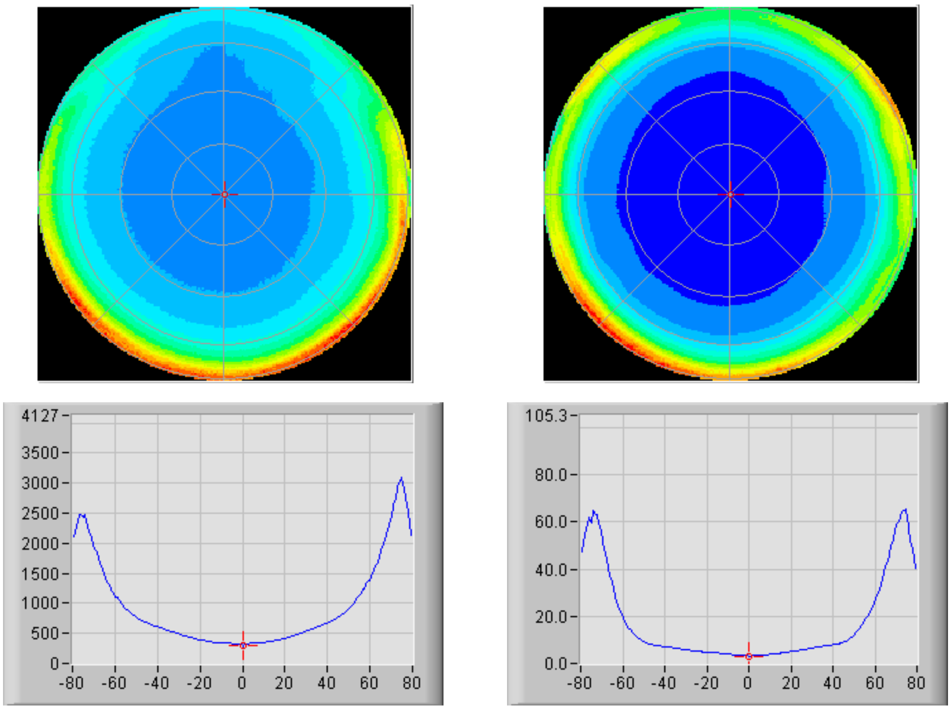
5.4.2 The Viewing Angle

The viewing angle of the reflective mode with cross linear polarizers is narrow and shown in Fig. 5.8(b). As mentioned in the previous works [5], the reflector plays an important role on the optical performance, such as viewing angle and contrast ratio. The viewing angle of the emission mode, shown in Fig. 5.8, is about 160°. The reason of the wide viewing angle of emission mode can be attributed to the property of self-emission. By comparing Figs. 5.8 (a) and (b), the measurement result with segment recorder does not alter the light distribution and only eliminates the surface reflectance.



(b) (b)

Fig. 5.9 The viewing angle of the reflective mode with (a) one circular polarizer and (b) two cross linear polarizers



(a) (b)

Fig. 5.10 The viewing angle of the emission mode (a) with and (b) without segment recorder

5.4.3 The Visual Performance

The actual images of emi-flective display in both the reflective and emission mode are shown in Fig.5.9. As shown in Fig. 5.10, the emi-flective display demonstrates the operation of top emission OLED after the integration of R-LCD.

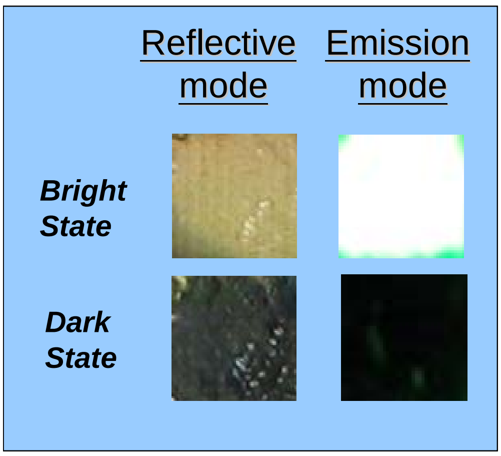


Fig. 5.11 The photograph of the reflective and emission mode

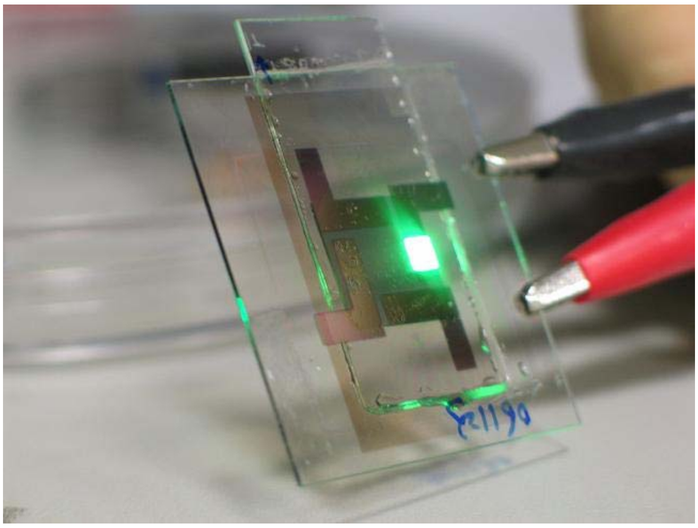


Fig. 5.12 The photograph of the emi-flective display

5.5 Discussion

5.5.1 The Optical Performance

Although the integration of top emission OLED and R-LCD without intermediate glass is first demonstrated by FPD system lab, NCTU, the idea of combination of OLED and LCD was first proposed by E. Lueder in 2000 [24]. After that, several reports of stacking device were presented, for instance, Mutsumi Kimura and Yeh-Jiun Tung proposed hybrid display composed of LCD and OLED [25]. A. Mosley brought up the idea of reflective OLED as the backlight of transflective LCD [26]. Jiun-Haw Lee discussed about the tandem structure of RLCD and OLED[27].

With the transflector, the cathode of the top emission OLED, the ambient light is reflected by the transflector. As shown in Fig. 5.12, the aperture ratio in reflective mode is not sacrificed by the circuitry. As shown in Fig. 5.13, the configurations of the proposed hybrid displays are with four substrates. The components of OLED and R-LCD are fabricated separately and integrated. Therefore, the proposed hybrid displays require two circuitry planes to drive OLED and R-LCD. From the structures of the proposed hybrid displays, the aperture ratio in both the reflective and emission modes is sacrificed by two circuitry planes. As only requiring one circuitry plane, the emi-flective display has the advantage of low cost. In conclusion, the emi-flective display has the benefits of low cost, high aperture ratio, thickness. The comparison of different hybrid display structures is shown in Table 5.4.

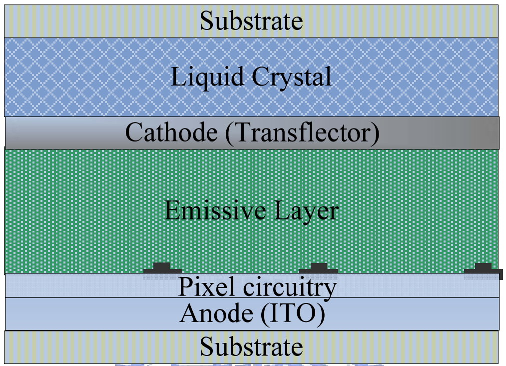
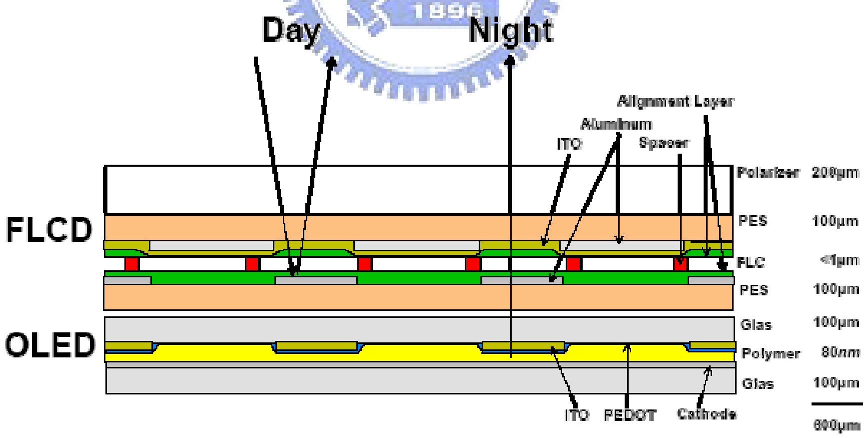
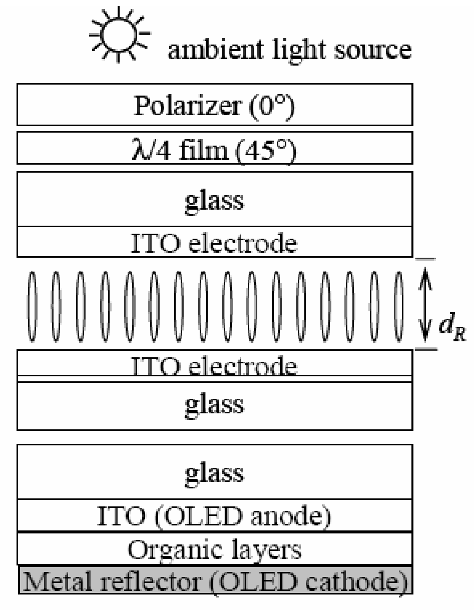


Fig. 5.13 Schematic diagram of the emi-flective display



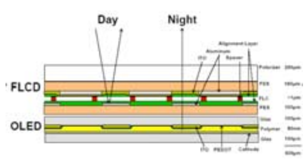
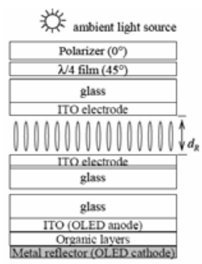
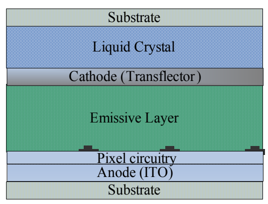
(a)



(b)

Fig. 5.14 Configurations of hybrid displays proposed by (a) E. Lueder and (b) Jiuw-Haw Lee.

Table 5.4 The comparison of different hybrid display structures

Design	The Combination of Transflective FLCD with OLED	Tandem Reflective Liquid Crystal Display and OLED	The Emi-flective Display of Top Emission OLED and R-LCD
Design			
Author	E.Lueder	Shin-Tson Wu et al,	FPD Lab, NCTU
Configuration	LCD on OLED	LCD on OLED	LCD on OLED
Number of Substrates	Four	Four	Two
Number of the circuitry planes	Two	Two	One
Aperture Ratio	Low	Low	High

5.5.2 The Electrical Performance

After the integration of top emission OLED and R-LCD, the deviated electrical characteristic of top emission OLED is observed. On the other hand, the poly-Si TFTs suffer the effect of the threshold voltage variation due to re-crystallization process. In order to improve the uniformity of displayed images, the above effects should be taken into consideration. As shown in Fig. 5.14, the proposed circuit which can compensate the deviated electrical characteristic of top emission OLED, threshold voltage variation of poly-Si TFTs. For the pixel circuit of the hybrid displays, Mutsumi Kimura also proposed the pixel circuit in 2002, shown in Fig. 5.15(a) [25]. After that, Jiun-Haw Lee also refereed to another pixel circuit, shown in Fig. 5.15(b) [27]. The pixel circuit proposed by Mutsumi Kimura adopts SRAM to provide constant voltage on both OLED and R-LCD. Therefore, the grayscale is determined by the displayed area which lowers the definition of the hybrid display. Moreover, the deviated electrical characteristic of OLED can not be compensated by this pixel circuit. The pixel circuit referred by Jiun-Haw Lee is a combination of conventional pixel circuits of OLED and LCD. Compared to one proposed by Mutsumi Kimura, the conventional pixel circuit achieves grayscale by controlling data voltage. However, this pixel circuit has the shortcomings of the immunity of the threshold voltage variation and the deviated electrical characteristic of OLED. The comparison of different pixel circuits for hybrid displays is listed in Table 5.5.

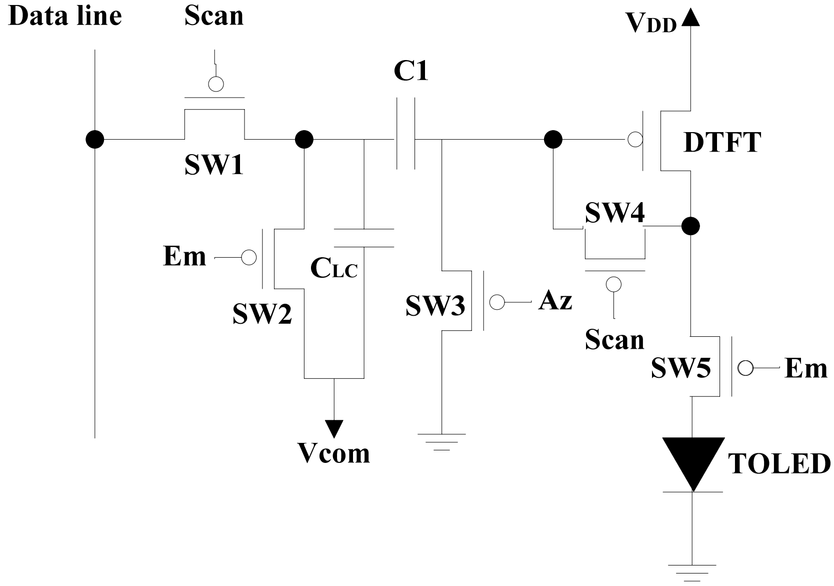
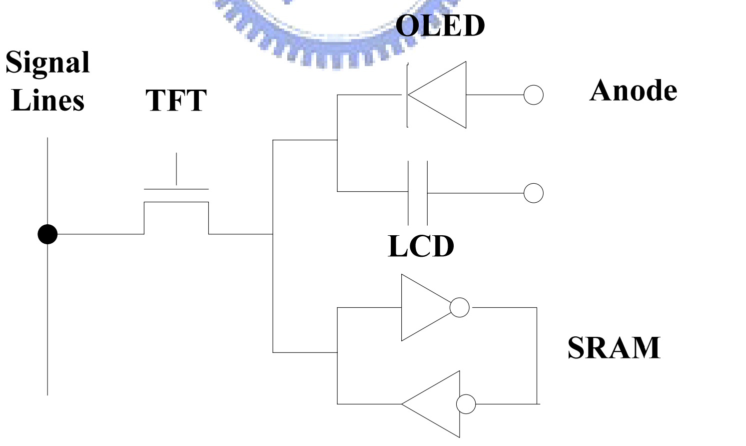
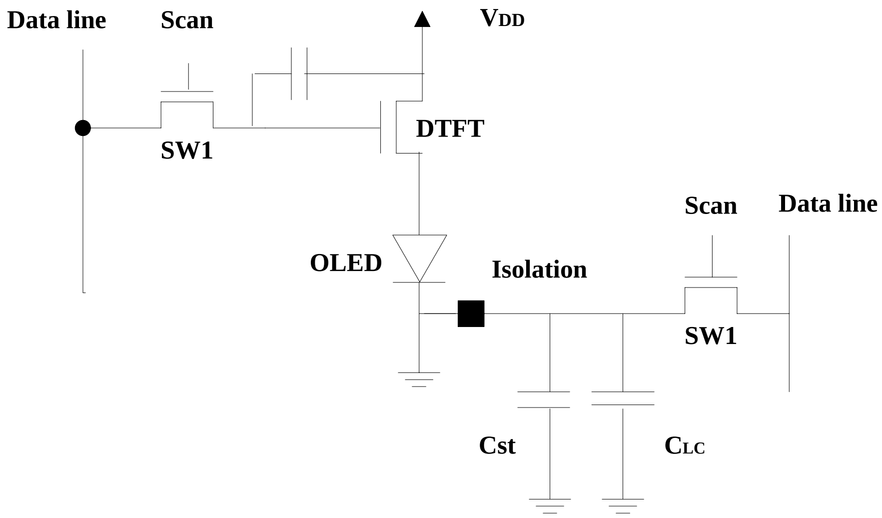


Fig. 5.15 The diagram of the proposed pixel circuit



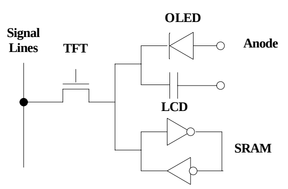
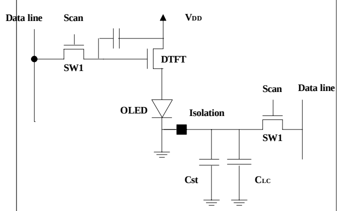
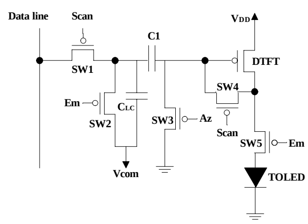
(a)



(b)

Fig. 5.16 The pixel circuits proposed by (a) Mutsumi Kimura and (b) Jiun-Haw Lee

Table 5.5 The comparison of different pixel circuits for hybrid displays

Design	Hybrid Display using LCD and OLED	Tandem Reflective Liquid Crystal Display and OLED	The Emi-flective Display of Top Emission OLED and R-LCD
			
Author	Mutsumi Kimura	Shin-Tson Wu et al,	FPD Lab, NCTU
Grayscale	Area	Data Voltage	Data Voltage
Aperture Ratio	Low	Low	High
Immunity to Vth Variation	No	No	Yes
Immunity to OLED Degradation	No	No	Yes

As a result of low contrast in the reflective mode, the reflective liquid crystal display needs to be optimized. In addition, two cross polarizers applied to R-LCD cause the parallax to reduce resolution and reduce reflectivity. The mixed twist nematic (MTN) R-LCD is adopted to enhance the contrast ratio. The advantages of high reflectivity, low color dispersion, fast response time, and one linear polarizer can be achieved by the 63.6° MTN R-LCD. With the parameter of the pretilt angle and liquid crystal, the optimized 63.6° MTN R-LCD with the cell gap of 2.3μm, shown in Fig 5.16, is designed to replace the R-LCD part of the emi-flective display. As shown in Fig. 5.17, the simulated contrast ratio of optimized MTN R-LCD and fabricated TN R-LCD are presented at the wavelengths of 450nm, 550nm, and 650nm. At a wavelength of 550nm, the contrast ratio of the optimized MTN R-LCD is 10:1 at the viewing cone of ± 60 degree. Compared to the fabricated TN R-LCD, the contrast ratio larger than 2:1 can be maintained at different wavelengths in the optimized MTN R-LCD.

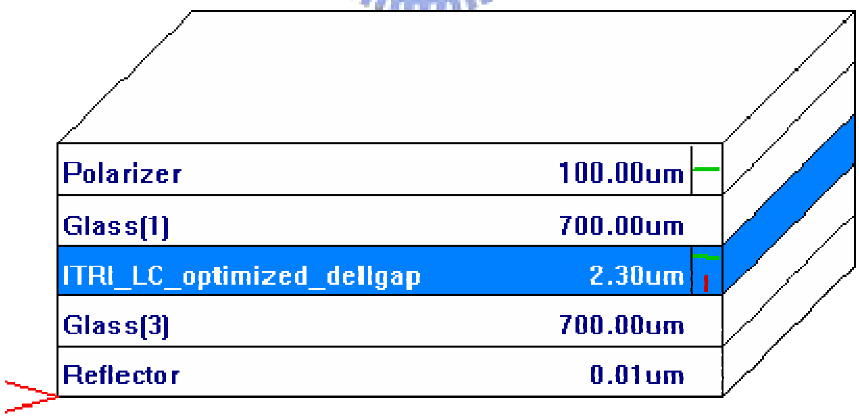


Fig. 5.17 The schematic diagram of the optimized structure in the reflective mode

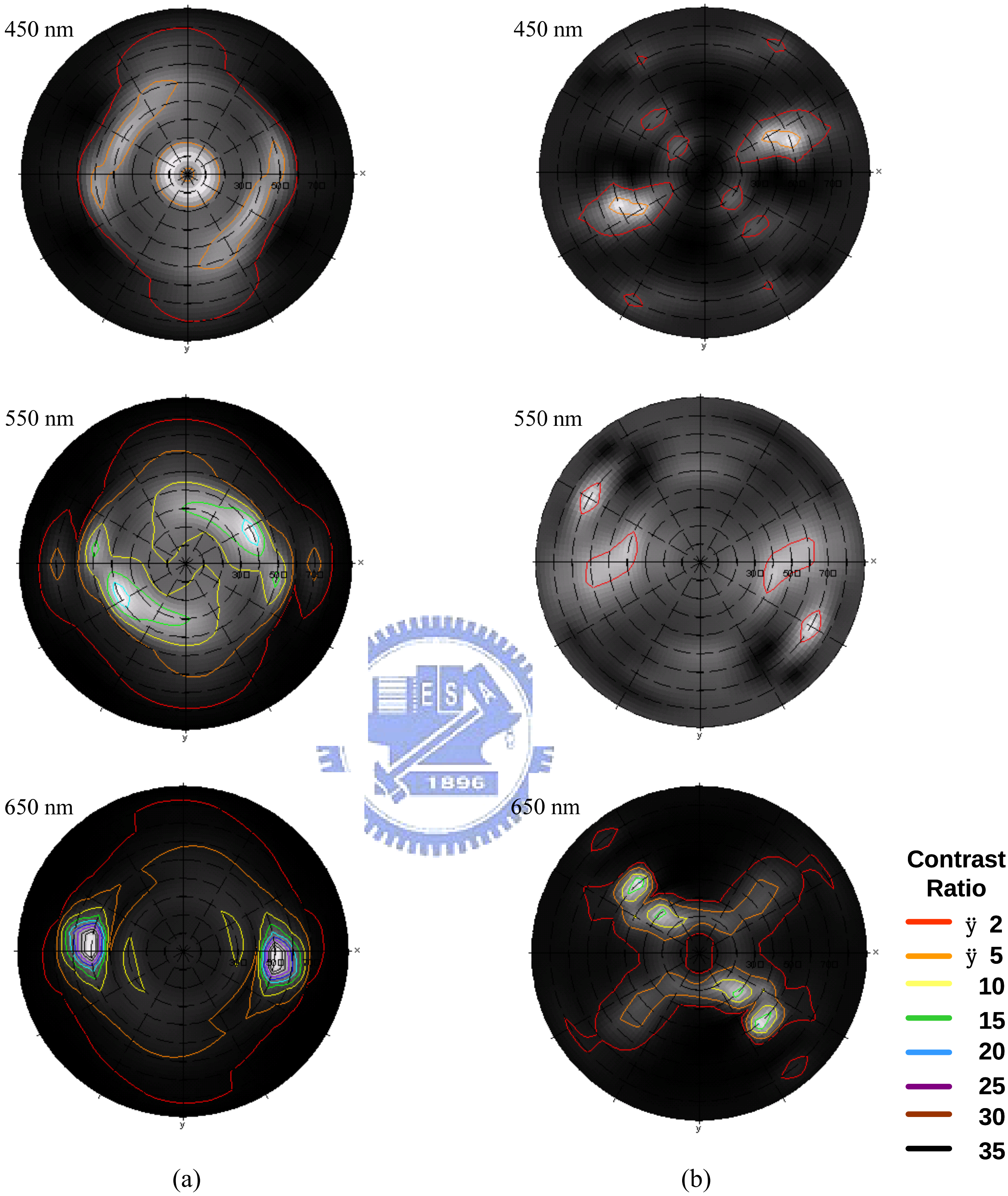


Fig. 5.18 The simulated contrast ratio of (a) optimized MTN R-LCD and (b) fabricated TN R-LCD at the wavelengths of 450, 550,and 650 nm

5.6 Summary

In this section, the optical performance, surface profiles and electrical characteristics of the emi-flective display were evaluated. Although low contrast ratio suffers from the large cell gap of $5\mu m$, the emi-flective display without intermediate glass is demonstrated and feasible for active matrix displays. According to the deviated electrical characteristics, the pixel circuit is proposed and verified by the software Hspice. With the aid of the structure of the emi-flective display, aperture ratio is not sacrificed by the number of the TFTs and capacitors on the circuitry plane.