12-2: Multi-domain Vertically Aligned LCDs with Super-wide Viewing Range for Gray-scale Images

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Abstract
We have developed a multi-domain vertically aligned liquid crystal display (MVA-LCD) that produces natural gray-scale images even at high viewing angles. We divided each pixel into two areas and set different threshold voltages for each sub-area. A transparent electrode in a sub-area is not connected directly to the source electrodes but via the capacitance of the SiN layer. In particular, light-orange skin color appears very natural, even at a high inclination angle. The contrast ratio is over 500 in the normal direction and over 10 from any viewing angle.

1. Introduction
Liquid crystal displays are now used for mobile phones, note PCs, desktop monitors, and large television sets. To provide a wider viewing range, Fujitsu commercialized a multi-domain vertically aligned liquid crystal display (MVA-LCD) in 1997 [1]. In-plane switching, using single-domain[2] and multi-domain technology,[3] became available in 1997 and 2000, respectively, and is now used world-wide. In particular, 80% of television sets incorporate MVA technology. MVA has almost perfect viewing angle characteristics; the contrast ratio in the normal direction is over 700, and over 10 from any viewing angle (an inclination angle of over 85 degrees for any viewing azimuth). However, a notable weak point is that the skin color of Asian people (light orange or pink) appears bluish or whitish from an oblique viewing direction. This phenomenon is termed color wash-out. We have tried to improve on this feature.

2. Principle
The transmittance-voltage (T-V) characteristics of MVA in the normal direction is shown by the solid black line in Fig. 1-1. The transmittance changes monotonically as the applied voltage increases. However, in the oblique direction, it winds and the various gray scales become the same, changing the displayed color (dashed red line in Fig. 1-1). To improve on this feature we tried combining two different T-V characteristics. The original idea was put forward in relation to TN-LCDs[4]. The dotted red line in Fig. 1-2 shows the original T-V characteristics in the oblique direction. The thin blue line in Fig. 1-2 shows other T-V characteristics with a higher threshold voltage. By optimizing the threshold voltage and maximum transmittance of these two lines, monotonic characteristics can be realized, as shown by the bold solid green line in Fig. 1-2. We call this technology half-tone technology.

3. Experimental

3.1 Driving technology
We initially tried to develop the half-tone technology by using a special driving pattern. We produced gray scales by combining two different gray scales (Fig. 2). Figure 2-1 shows a simple example of a 64th/256 gray scale where 3rd and 178th/256 gray scales are combined. When we changed the gray scale using two frames, flicker occurred. We therefore divided all the pixels into two groups, A and B (Fig. 2-2). Each group has a mosaic-like pattern. In Group A, the gray scale alternates between lower and higher gray scales, and in Group B it operates in reverse, i.e. it alternates between higher and lower gray scales. Although we were able to suppress flicker, the images did not look natural because the mosaic pattern was recognizable when we changed the viewing point following moving objects.

3.2 Pixel configuration
We then divided each pixel into two areas. One area had the original threshold voltage and the other area had a slightly higher one.

Figure 3 shows our initial idea. Figure 3-1 shows a cross-sectional view and Fig. 3-2 shows the equivalent electronic circuit. We added wide protrusions to the surface of the transparent electrodes of the TFT substrate. These protrusions covered almost half of each pixel. The applied voltage between the transparent electrode on the TFT and that on the CF substrate was divided due to the capacitance produced by the additional protrusions. Then the applied voltage, V2, in Fig. 3-1 for the liquid crystal layer in area B was lower than V1 in area A. This meant that the practical threshold voltage in area B was higher than in area A. In this case, the problem was that the cell gap in area A was different from that in area B.

Figure 4 shows our second and final idea. In this case, we used a SiN passivation layer to produce capacitance between the source electrode and transparent pixel electrode. The applied voltage V1 was divided into V2 and V3 due to the capacitance between the transparent electrode and the source electrode. As there was no additional material or protrusion, the cell gap in area A was the same as that in area B.

Figure 5 shows a microphotograph of a pixel with this technology. Figure 5-1 shows the black state, Figures 5-2 through 5-4 show the gray-scale states, and Fig. 5-5 shows the white state. The pixel is divided into two areas and each has a different threshold voltage. To keep the symmetrical viewing angle characteristics.

each sub-pixel is divided into four areas and the LC molecules are inclined to four different azimuths when voltage is applied. As Figs. 5-2 and 5-3 clearly show, gray-scale images are produced using both darker and brighter gray-scales. We called this new MVA system, MVA Super Premium.

3.3 22WXGA display and performance

We fabricated a 22W display and compared the viewing angle characteristics with those of conventional MVA and commercialized Super IPS (SIPS) systems. Figures 6-1, 7-1, and 8-1 show the performance of conventional MVA; Figs. 6-2, 7-2, and 8-2 show that of MVA Super Premium; and Figs. 6-3, 7-3, and 8-3 show that of Super IPS. Figure 6 shows the contrast ratio for black and white display images. In the normal direction, the contrast ratio is over 500, and over 10 at any viewing angle (an inclination angle of over 85 degrees in any viewing azimuth direction), as shown in Fig. 6-2-2. The color coordinates of the pure colors (black, white, red, green, and blue) were measured (Fig. 6-2-1). The new MVA showed the least color change of the three different displays.

Figure 7 shows an image from the fabricated display. To check the viewing angle characteristics, we used a picture of an Asian woman and checked changes in skin color (light orange or pink), because we wanted to ensure that Asian skin tones were displayed accurately. In the case of conventional MVA, the color was slightly whitish and the SIPS system showed a reddish color; both looked unnatural. The new MVA with half-tone technology showed little color change and the image was very natural. Figure 8 shows the measured color and the changes in the u'v' color coordinates. With the new MVA, the u'v' changed only slightly and the color itself was almost the same as that in the normal viewing direction.

We compared the overall performance of the new MVA and SIPS systems. The results are summarized in Table 1. The contrast ratio and transmittance in the normal direction was much higher for the MVA system than for SIPS. The skin color appeared very natural from any viewing angle. The details of a dark image were distinguishable, unlike the results for SIPS.

4. Conclusion

We developed a new MVA (MVA Super Premium) that solves the problem of color wash-out. We combined darker and brighter gray scales to produce intended gray scales. After trialing a special driving scheme (new pixels with additional protrusions), we concluded that it was best to utilize the capacitance produced by the SiN passivation layer. When an image of an Asian woman was displayed, the light-orange skin color appeared very natural even at high viewing inclination angles. The contrast ratio was over 500 in the normal direction and over 10 from any viewing angle.

5. Acknowledgement

The performance of the new MVA was evaluated by AU Optronics (AUO), who made several suggestions. Our thanks to the engineers at AUO.

6. References

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[2] M. Ohta, M. Oh-e, and K. Kondo, Digest of Asia Display '95, 707 (1995).

[3] Y. Mishima, T. Nakayama, N.Suzuki, M. Ohta, S. Endoh, and Y. Iwakabe, SID '00 Digest, 260 (2000).

[4] K.R. Sarma, R.I. McCartney, B. Heinze, SID'91 Digest, 555 (1991)

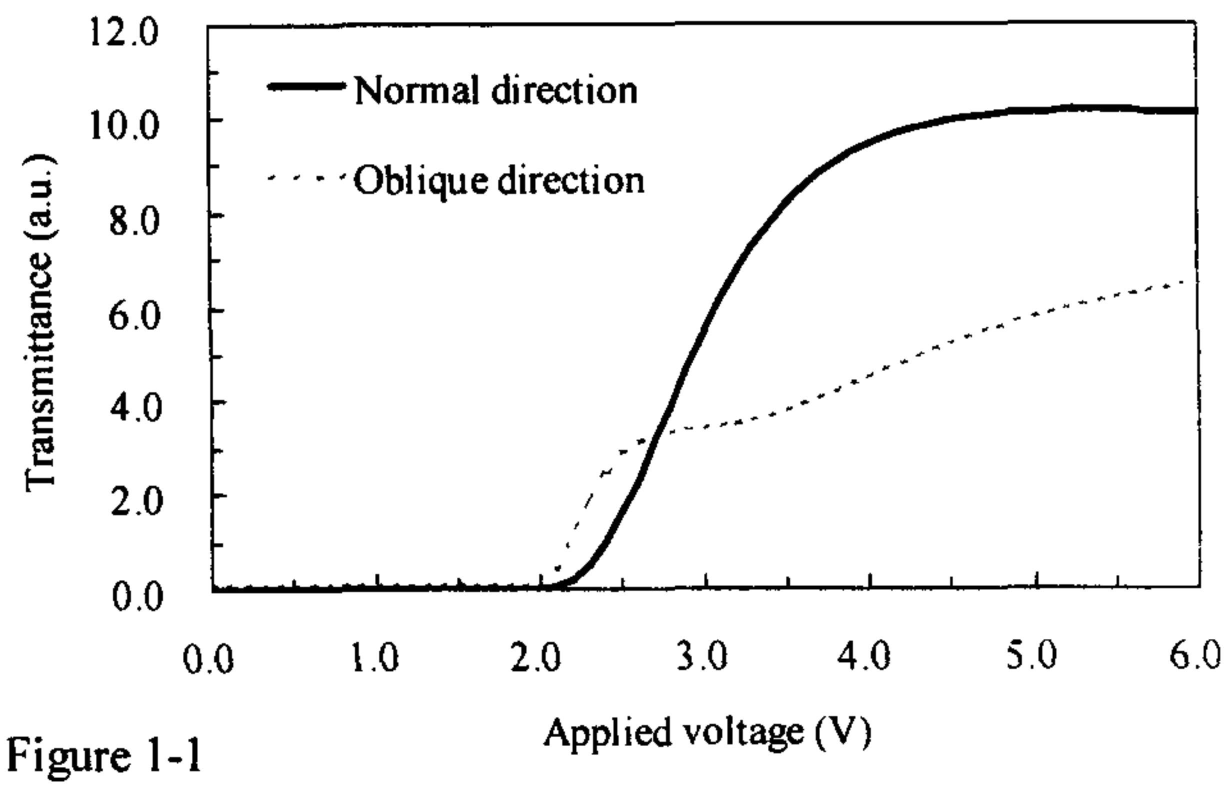


Figure 1-1

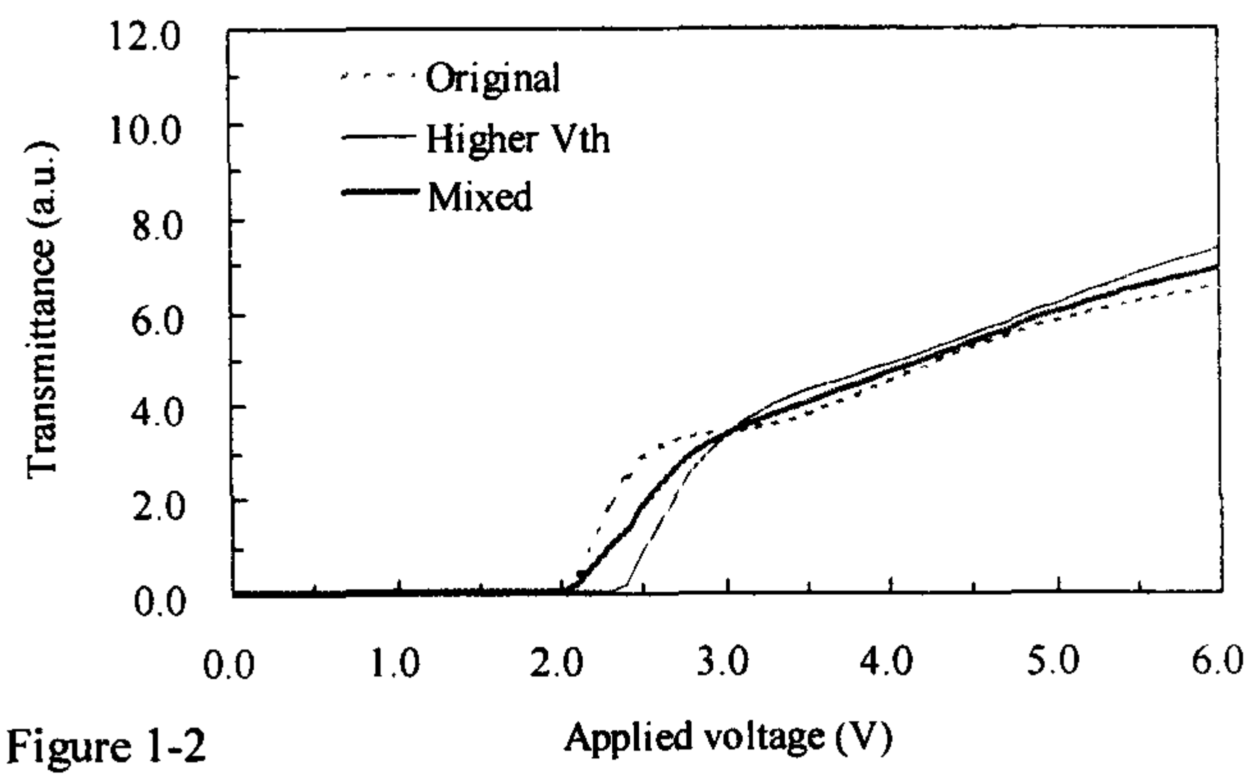


Figure 1-2

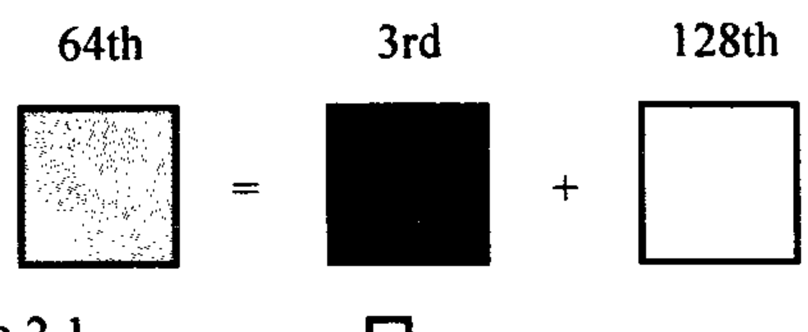


Figure 2-1.

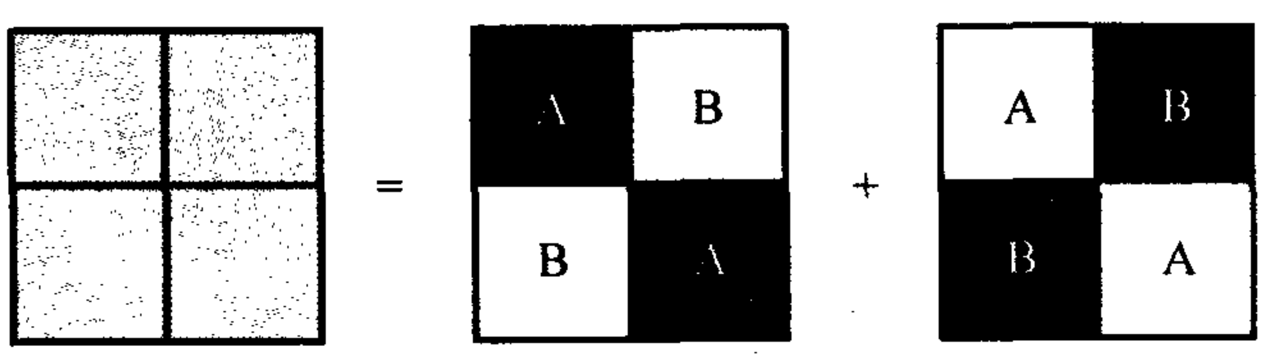


Figure 2-2. Mozaic pattern is recognizable.

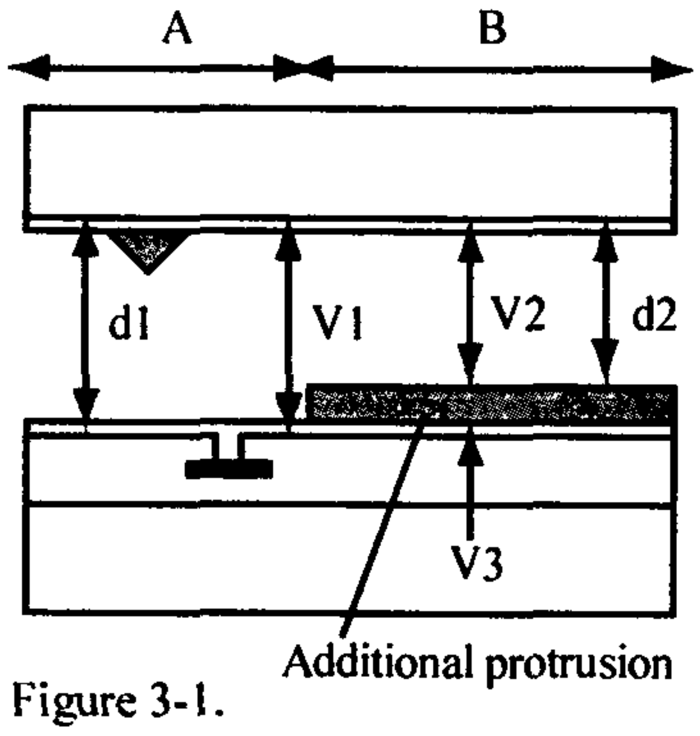


Figure 3-1.

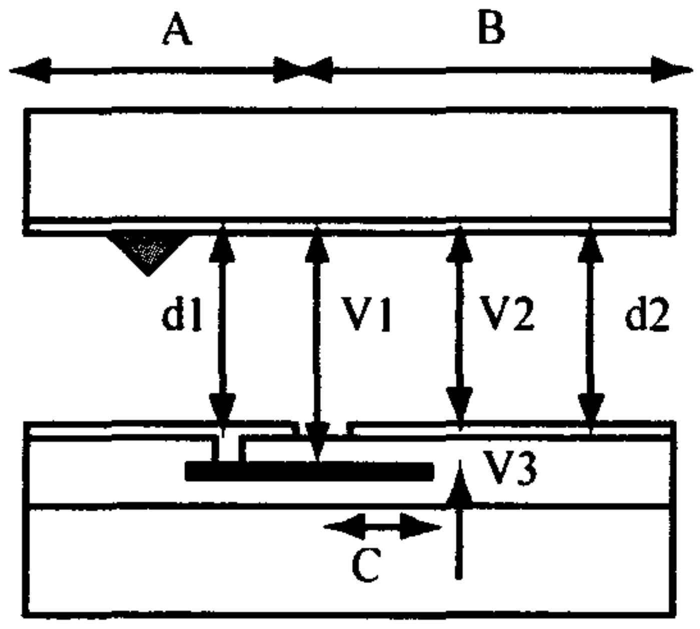


Figure 4-1.

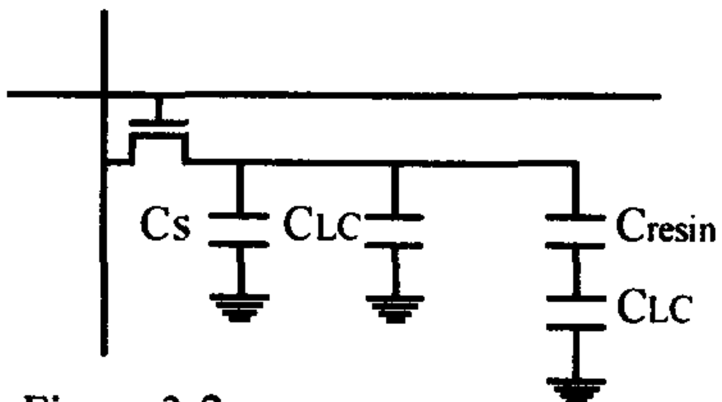


Figure 3-2.

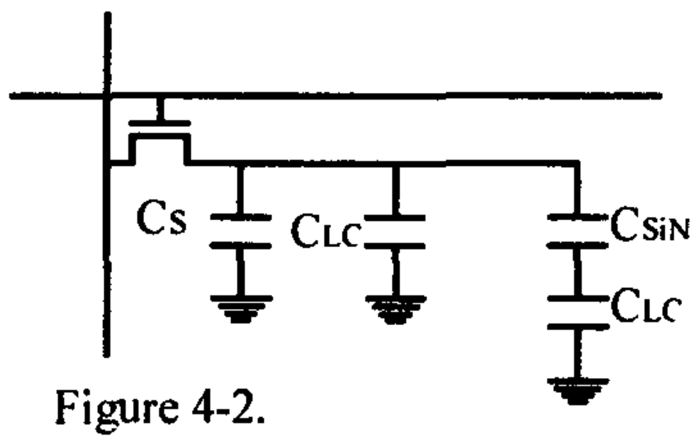


Figure 4-2.


Figure 5-1.

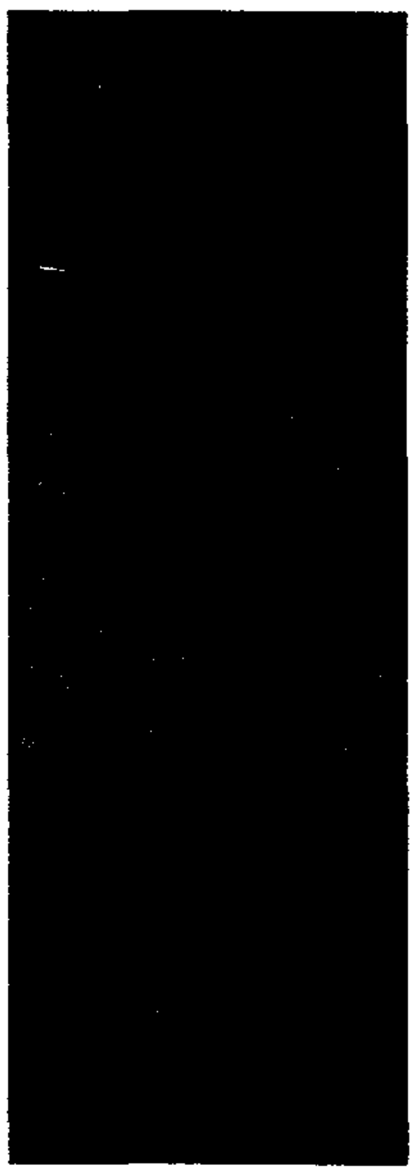


Figure 5-2.


Figure 5-3.


Figure 5-4.

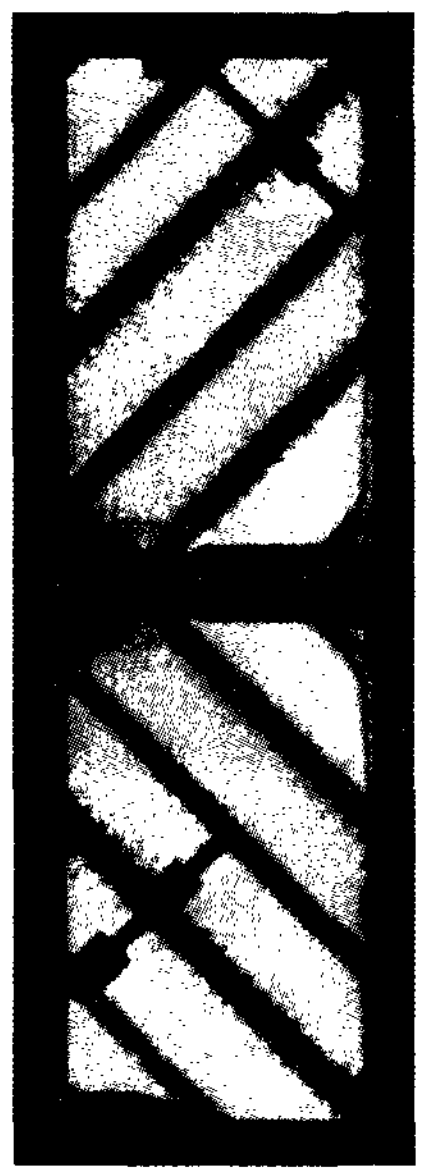


Figure 5-5.

Table 1

Optical performance		Conventional MVA	New MVA	SIPS
Contrast (normal)		Excellent (700-900)	Excellent	Good (around 300)
Brightness (power consumption)		Excellent	Good	Fair (1/2 of MVA)
Color shift (Viewing angle)	Pure color (R, ,B)	Excellent	Excellent	Fair (change)
	Black	Excellent	Excellent	Poor (major change to reddish or bluish)
	Skin color (right-orange)	Fair (wash out)	Excellent (natural)	Good (Reddish)
Near black reproducibility		Good	Good	Fair (details cannot be distinguished)

Conventional MVA | MVA Super Premium | S-IPS

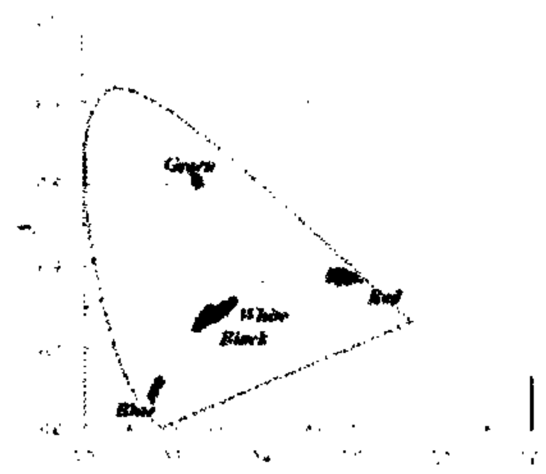
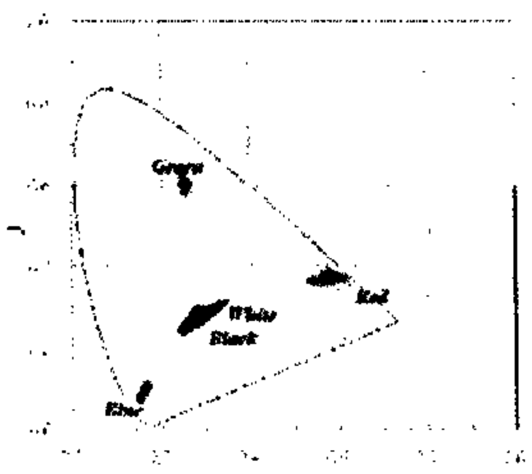


Figure 6-1-1



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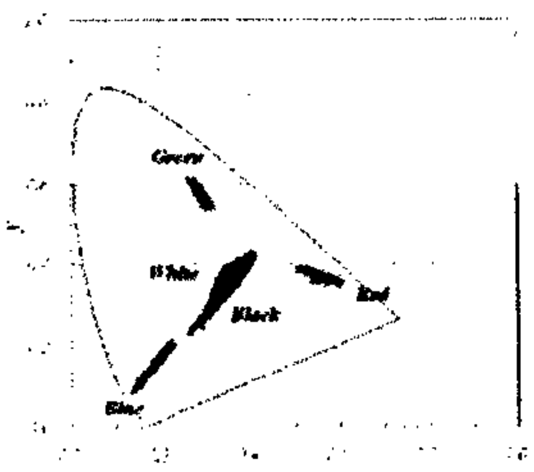
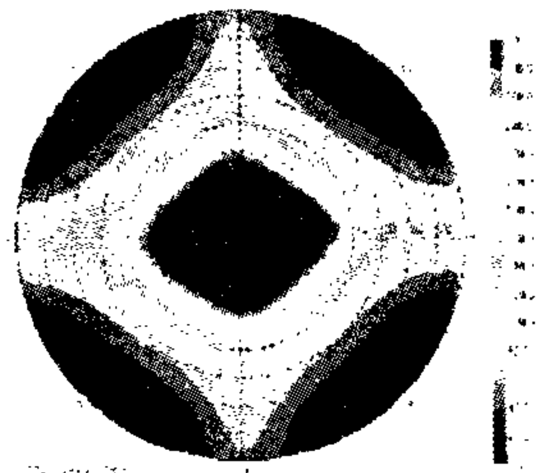


Figure 6-3-1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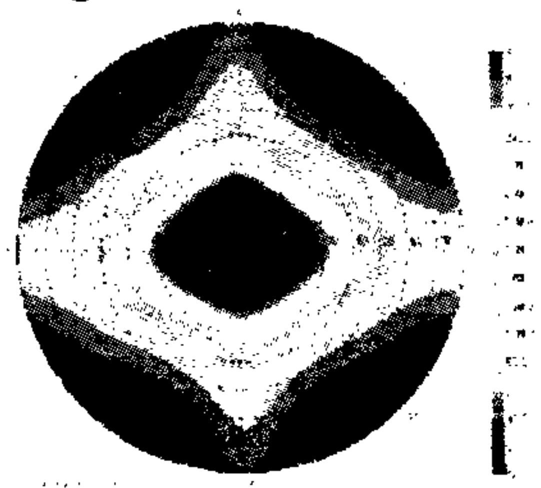
Figure 6-2-2

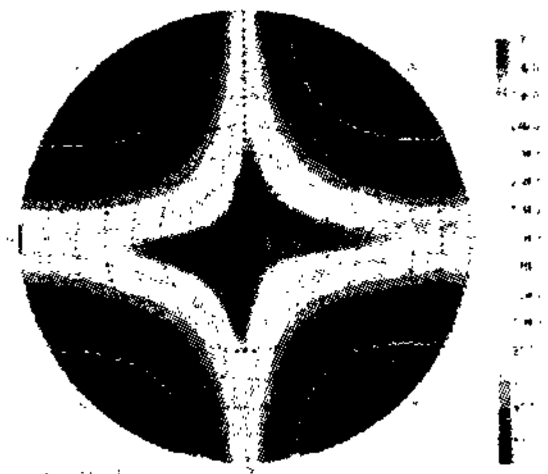
Figure 6-3-2

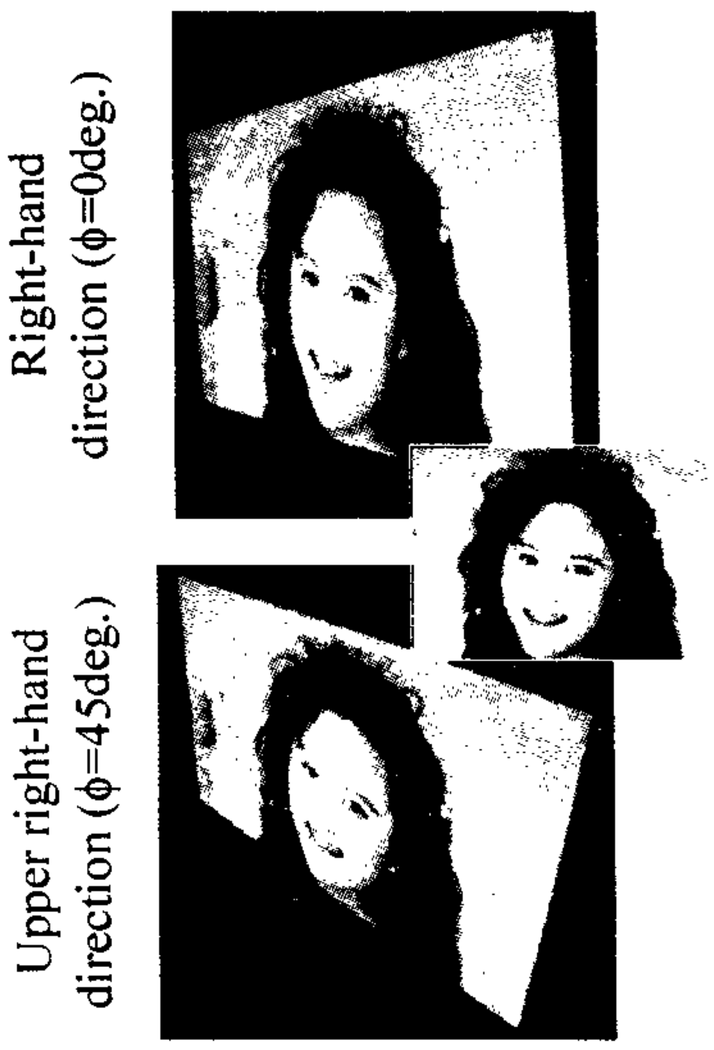

Figure 7-1

Figure 7-2

Figure 7-3

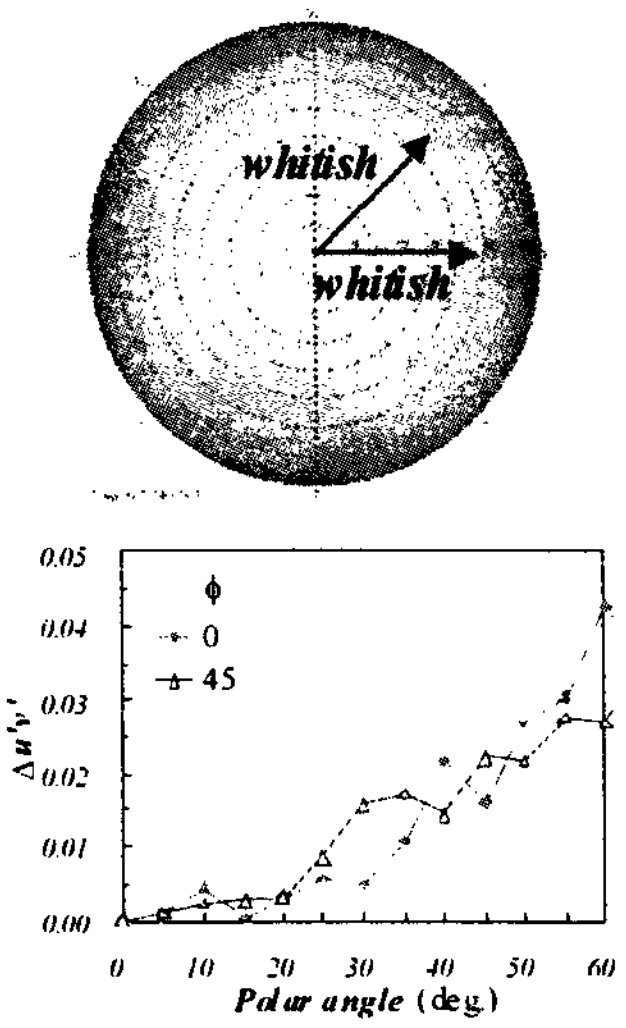

Figure 8-1

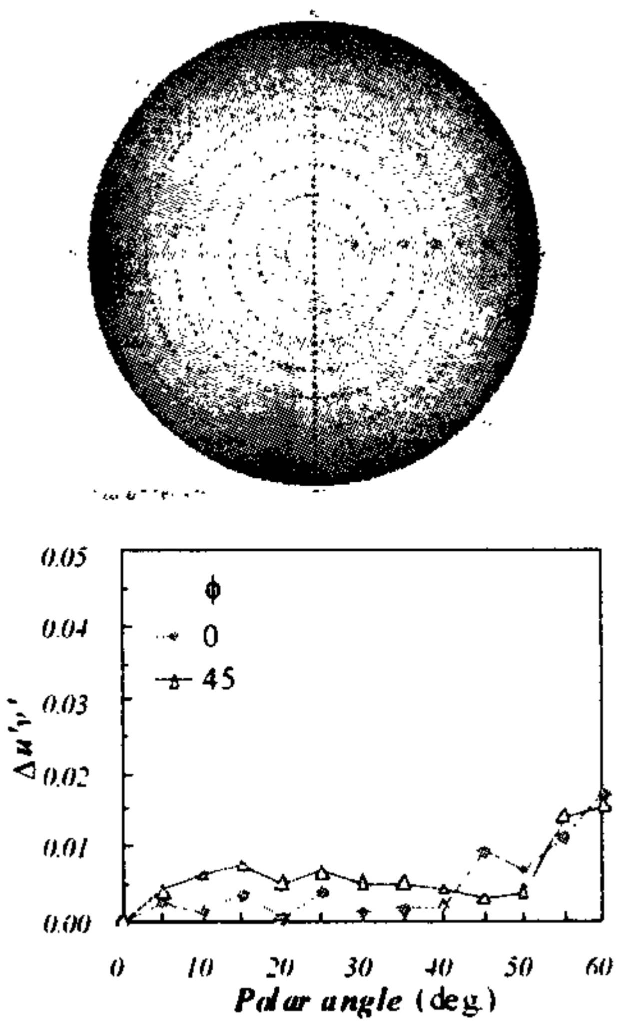

Figure 8-2

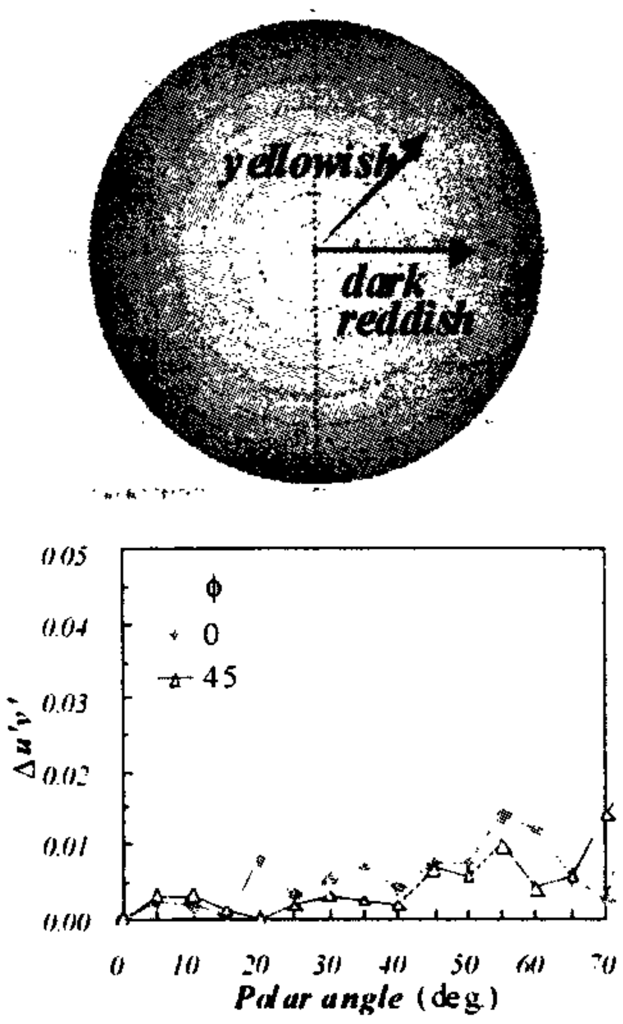

Figure 8-3