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A High Quality Fringe-Field Switching Display for Transmissive and Reflective Types

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Abstract

In liquid crystal displays, the display mode that represents initial liquid crystal alignment and method of applying voltage, mainly determines the image quality of display. Recently we have developed the fringe-field switching (FFS) mode exhibiting high image quality. In this paper, a pixel concept, manufacturing process, materials, and electro-optic characteristics of the FFS mode comparing with conventional in-plane switching mode, and its possible application to reflective type are discussed.

Keywords : Liquid crystal display (LCD), fringe-field switching (FFS), transmissive and reflective display

Ⅰ. Introduction

Recently, the market of liquid crystal display (LCD) is growing fast in liquid crystal TV as well as in monitors. In order to accelerate the replacement of CRT to LCD in monitor as well as TV field, lowering cost and improving image quality are necessary. Pursuing a high quality active matrix LCD (AMLCD), we have developed new wide-viewing-angle technology, fringe-field switching (FFS)[1-5], showing unique electro-optic characteristics while keeping the liquid crystal (LC) director to rotate in-plane as in the conventional IPS mode [6]. We have already manufactured 15.0" and 18.1" TFT-LCDs for transmissive type and 15.0" for reflective type utilizing the FFS mode. The module shows wide-viewing angle, high transmittance, low crosstalk, and relatively fast response time in grey scales. The reflective display also shows wide viewing angle owing to in-plane orientation. The FFS mode is also becoming popular such that the results about the FFS device from others are being reported. In this paper, the overall characteristics of the FFS mode and possible application to reflective LCD are reviewed.

2. Characteristics of the FFS Mode

2.1 One pixel concept in array and cell structure

Considering one pixel of the FFS mode is an interesting concept. In the conventional IPS mode, the distance (l) between pixel and common electrodes is larger than that of the cell gap (d) and the width of pixel electrodes (w), resulting in horizontal field (E_y) with bias voltage. In this case, the storage capacitance (C_{st}) exists in non-active area, that is, the higher C_s, the lower the transmittance. However, the concept of interdigital electrodes in the FFS mode is discarded. Instead, there is no horizontal distance between pixel and common electrodes with passivation layer between them while the distance (l') between pixel electrodes exists with a ratio of electrode width to distance about 0.5~2. In this case, with bias voltage, the fringe field lines with vertical (E_z) and horizontal components are generated, as shown in Fig.1. Further, in the FFS mode, the C_{st} exists automatically in an active area without losing the aperture ratio. Also, it is much larger than that of the IPS mode. In the cell structure, the liquid crystal molecules are homogeneously aligned with optic axis coincident

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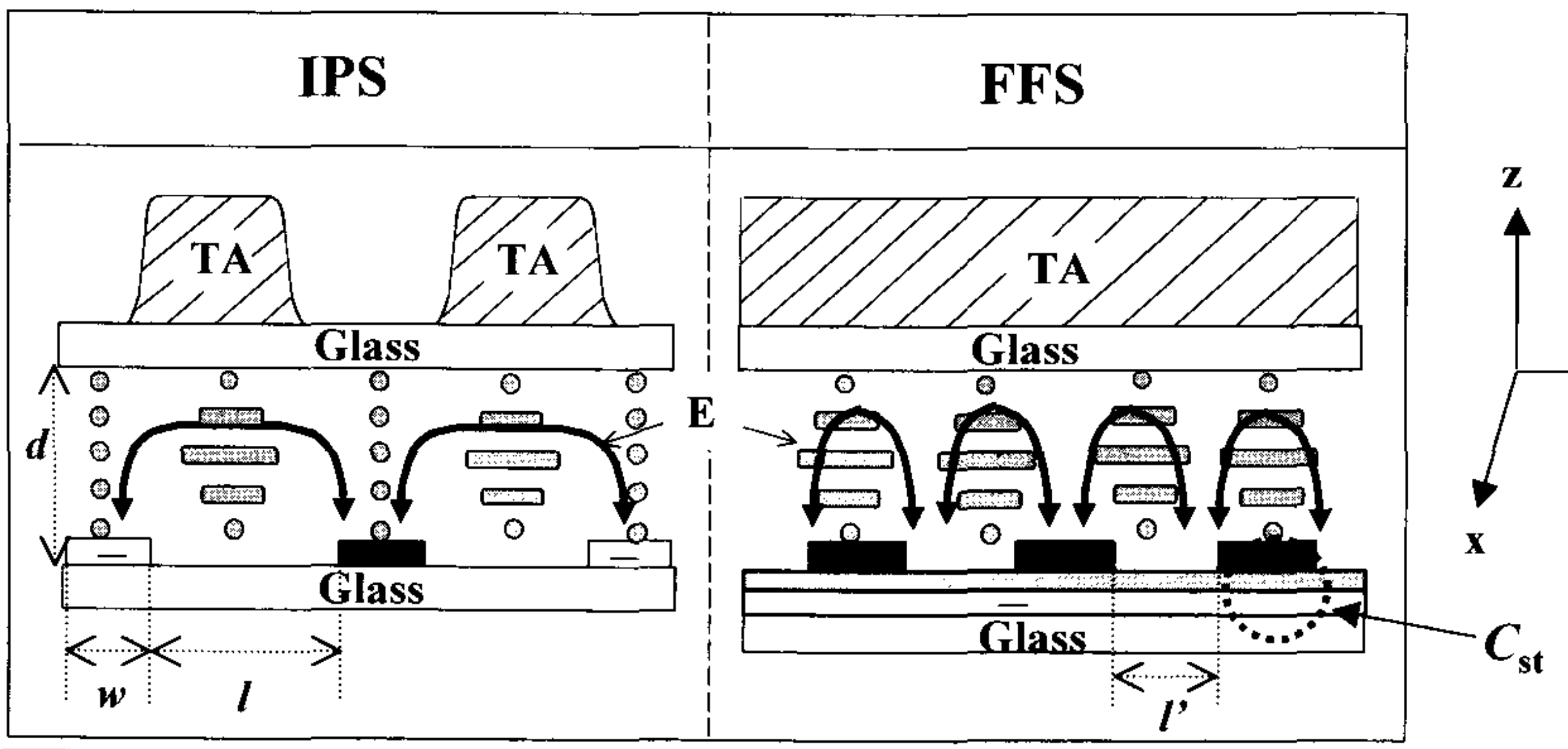
with one of the transmission axis of the crossed polarizers in the off state so that it appears black. With bias voltage, the fringe-field drives the LC director to rotate above whole electrodes, causing much higher transmitted area (TA) than the IPS mode as shown in Fig.1.

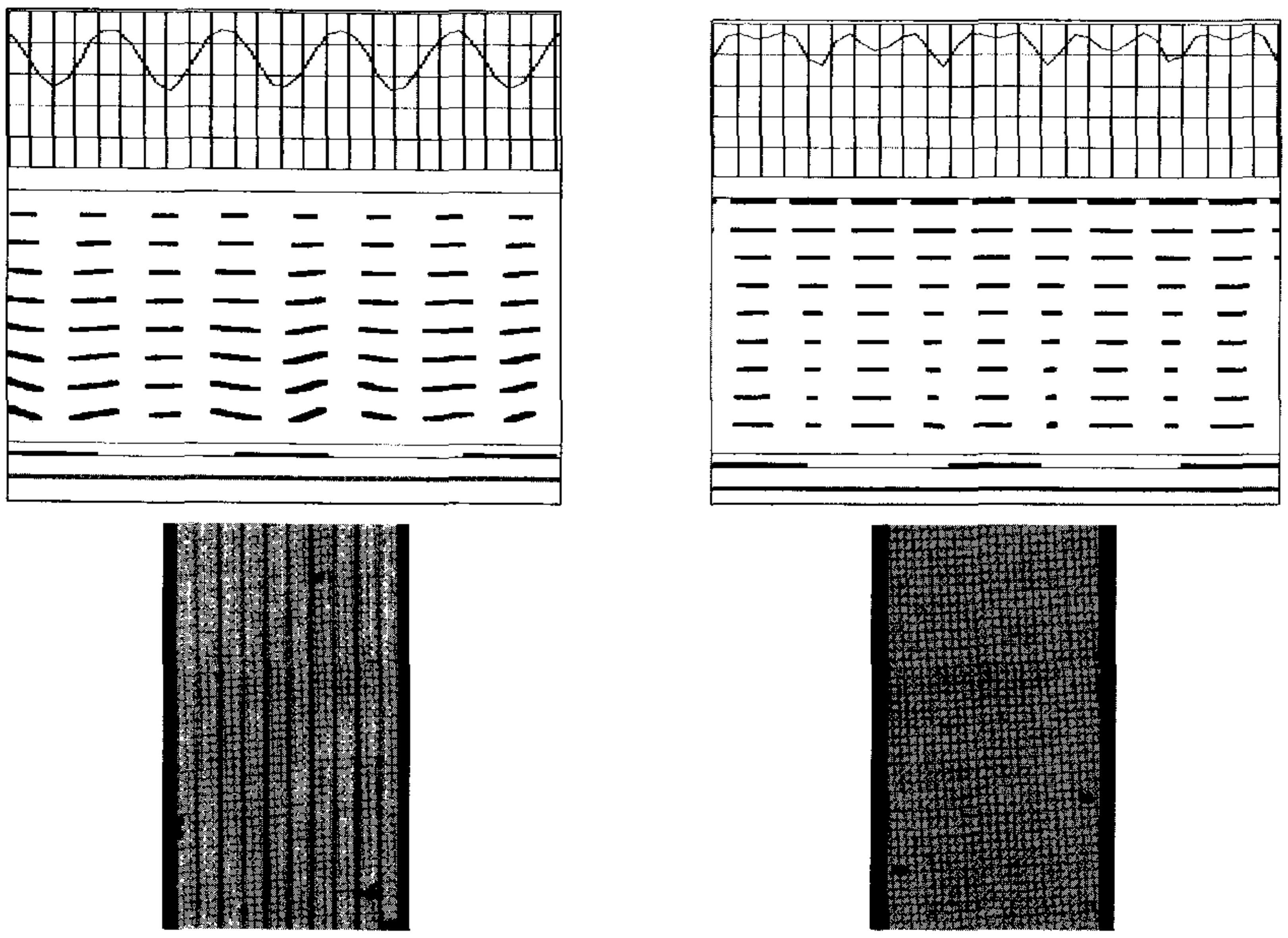
2.2 Process

In the array process of the FFS mode, two ITO layers are necessary since LC director modulates light even above electrodes which is the only demerit of the FFS mode, even though the ITO is not necessary for color



	IPS	FFS
l/d	>1	<1 or 0
l/w	>1	<1 or 0
Field	Ey	Ey, Ez
Electrodes	Metals or ITO	ITO

Fig. 1. Comparison of the IPS and the FFS modes indicating the differences in electrode structure and light transmitted area.



(a) (b)

Fig. 2. The simulational results and real pictures of one pixel for (a) the positive LC and (b) the negative LC.

filter side. Conventional twisted nematic (TN) mode needs ITO layers on top and bottom substrates, so the resulting number of ITO layers between TN and FFS modes are the same. In the IPS mode, the thickness of electrodes in light modulated area is at least above 1000Å since they are composed of opaque metals for gate and data bus lines. Consequently, a perfect alignment of the LC director near the electrodes is difficult unless the array substrate is planarized. However, in the FFS mode, the thickness of ITOs is only few hundred Å. So, good alignment of liquid crystal molecules with homogeneous alignment layers can be obtained without the planarization of the array substrate.

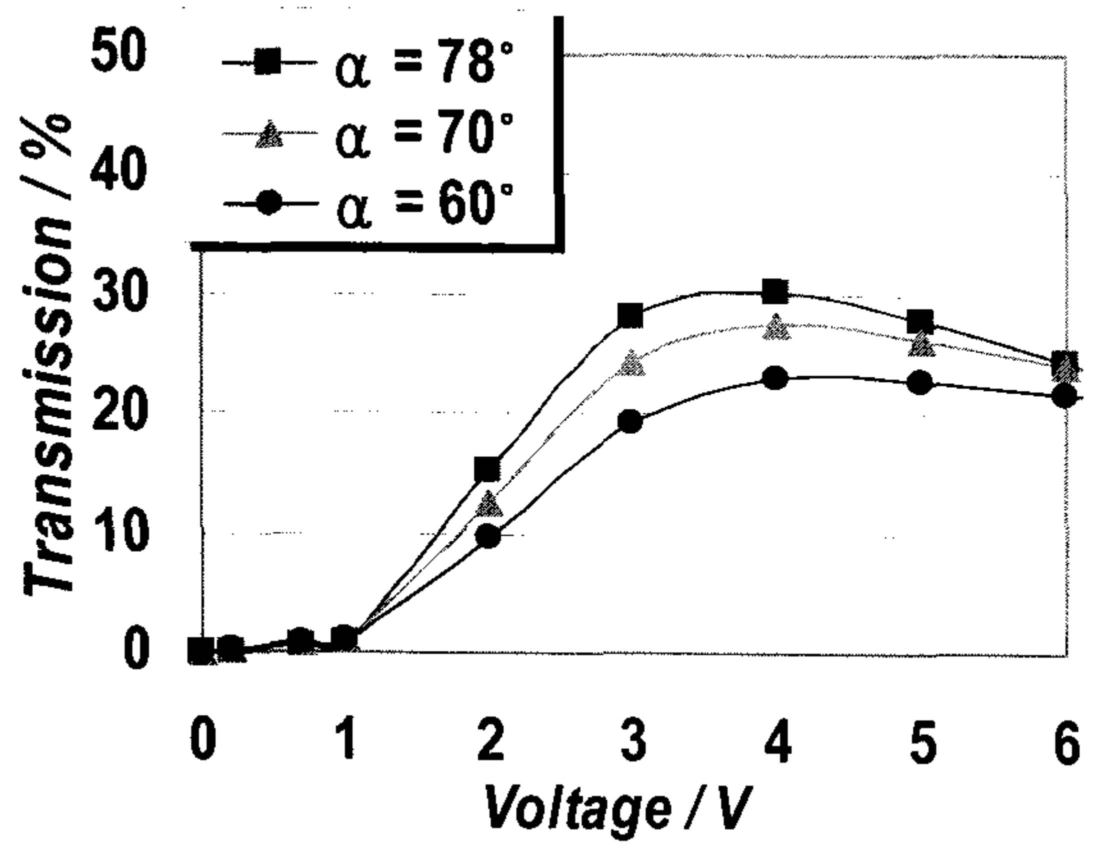


Fig. 3. The simulation results of voltage-dependent transmittance curves depending on rubbing angle(α).

TABLE Comparison of voltages at different greys for the cells with resin and Cr BM.

BM	V_{10}	V_{50}	V_{90}
Resin	2.21	3.30	4.88
Cr	2.21	3.31	4.90

2.3 Materials

2.3.1 color filter

In the IPS mode, the resin black matrix (BM), that is, a high specific resistance material, is required to block field disturbance caused by conductive chromium (Cr) BM. In the IPS mode, the cell gap is shorter than the distance between electrodes so that the field strength between common line and BM is stronger than that between electrodes. Consequently Cr BM disturbs in-plane field between electrodes, causing to increase operating voltage [7]. However, in the FFS mode there is no horizontal distance between pixel and common electrodes, that is, the field strength caused by Cr BM of upper substrate does not affect the field distribution in light modulated area.[8] We have checked the voltages at which the transmittance changes by 10%, 50%, and 90% for both cases and the results are almost the same as shown in table. When the Cr BM is used, the depth difference on overlapped area between color resin and BM and the LC modulated area is minimized. This allows for good alignment of LC molecules. This is another advantage of the FFS mode.

2.3.2 liquid crystal

In the FFS mode, both positive and negative dielectric anisotropy of the LC can be used. When the positive LC is used, the LC director tilts up along the fringe field line instead of rotation so that the degree of twist above center of electrodes is low, resulting in low transmittance. However, when the negative LC is used, the rotation of LC director occurs in the whole area, resulting in high transmittance. These phenomena are well illustrated in Fig. 2. For a cell with the positive LC, the light transmission oscillates like a sine function and is low above the center of electrodes. The photo of one pixel below simulational result also exhibits dark and bright striped lines along horizontal axis but such lines are not observed in a cell with negative LC. However, adjusting the phase retardation of the cell, physical properties of the LC, and electrode design can reduce the difference in light efficiency. With an optimized condition, it could be over 90% of that of the negative one. In the IPS mode, the light efficiency for both types of LCs is the same. Another distinct difference between the IPS and the FFS modes is voltage-dependent transmittance curves depending on rubbing directions. Fig. 3 shows that the transmittance decreases with decreasing rubbing angle (α) with respect to horizontal component of fringe field for the positive LC case, whereas it remains the same for negative LC one. Since the dielectric torque and the elastic force between neighboring molecules rotate the LC director in the FFS mode, the less elastic force caused by tilt-up molecules near the edge of the electrodes causes less twist deformation above the electrodes as the rubbing direction decreases for the positive LC. This result is very important in obtaining a FFS device with fast response time and high light efficiency because the rotational viscosity of the positive LC is less than that of the negative one at the present level.

3. Electro-optic Characteristics of the FFS Mode

3.1 Crosstalk

Another distinct characteristic of the FFS mode is crosstalklessness. The crosstalk is inversely proportional to total capacitance but is proportional to coupling capacitance between pixel and data bus line electrodes and fluctuation of pixel electrode potential in the case of dot inversion. As mentioned above, since the number of pixel electrodes in one pixel is more than 5, the C_{st} is much larger than that of the IPS mode. As a result, the fluctuation of a pixel potential is suppressed, so the crosstalk is less than 1%.

3.2 Viewing angle and color shift

Basically, the LC director in the FFS rotates in plane like the IPS cell except that the degree of twist alternates in the FFS mode. Such effect improves uniformity in brightness and results in less yellowish and bluish color change than that of the IPS cell. The contrast ratio greater than 10 exists over 80° in all directions.

3.3 Response time

In the FFS mode, the response time of the device depends on the design of pixel electrodes, the cell gap, viscosity and elastic constants of the LC. At the present level, the rotational viscosity of the negative LC is intrinsically higher than that of the positive one. Therefore, the rising and decaying response times of the FFS device with 90% change of light transmittance are 22ms and 28ms, respectively. However, with the use of the positive LC while manufacturing the same cell gap, the response time obtained was 32ms. Further, we will present the FFS device with 25ms in another publication.

4. Application of the FFS Mode to Reflective LCD (R-FFS)

The concept of in-plane orientation of LC director can be applied to a reflective LCD, owing to high transmittance characteristic of the FFS mode. Several types of the cell structures with one or two polarizers and with or without compensation films are possible. Fig. 4 shows a principle of operation for normally black mode with one polarizer (P) and λ /4 plate. In the off- state, the optic axes of the LC director and the P are coincident while having 45° between the P and the slow axis of λ /4 plate. Therefore, the polarization state of incident light passed quarter plate becomes circular and when reflected, the light with circularly polarization becomes linearly polarized after passing the retardation film. However, this linearly polarized light is 90° rotated so the polarizer blocks the light. For the bright state of the cell with a half-wave retardation, the optic axis of the half-wave LC layer is rotated by 22.5° by applying appropriate voltage to the cell. Then, the linearly polarized input light is rotated by 45° passing through the LC layer. At this point, the polarization is in parallel with the optic axis of the quarter-wave retardation film. Therefore, the light maintains polarization during the double pass through the quarter-wave film. And then, the reflected light is rotated by -45° by propagating through the LC layer once more. Finally, the reflected light is linearly polarized again, which is in parallel with the transmission axis of the polarizer. So, the bright state is achieved. Fig. 5 shows the simulational results of the device exhibiting viewing angle characteristics in horizontal and vertical directions based on Berreman's 4X4 method. The results show no grey scale inversion up to 60° of polar angle. Fig. 6 shows the voltage-dependent reflectivity curve, where the light source is located at a polar angle of −30° and is detected at a polar angle of 10°. The voltage showing maximum transmittance is only 3.5*V*. In conclusion, the R-FFS mode shows intrinsically no grey scale inversion over wide range owing to in-plane rotation, and also, low driving voltage since LC director rotates only by 22.5°.

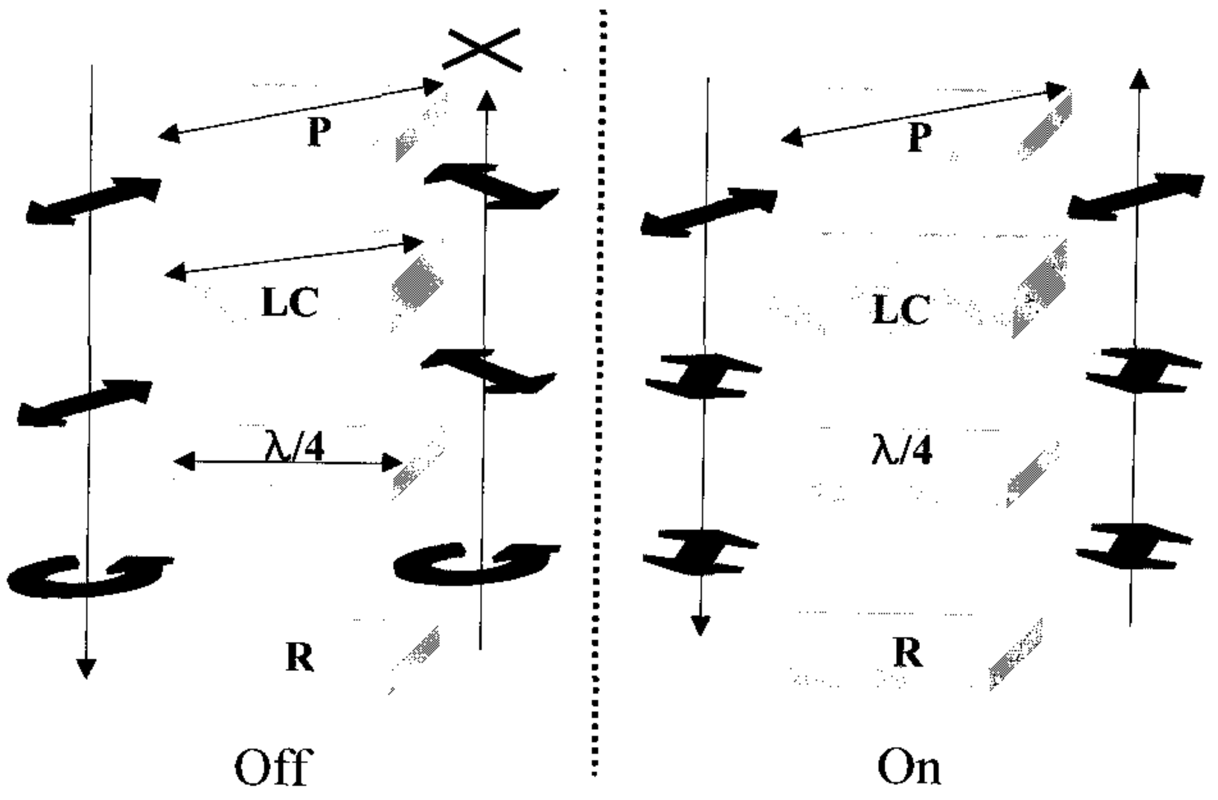
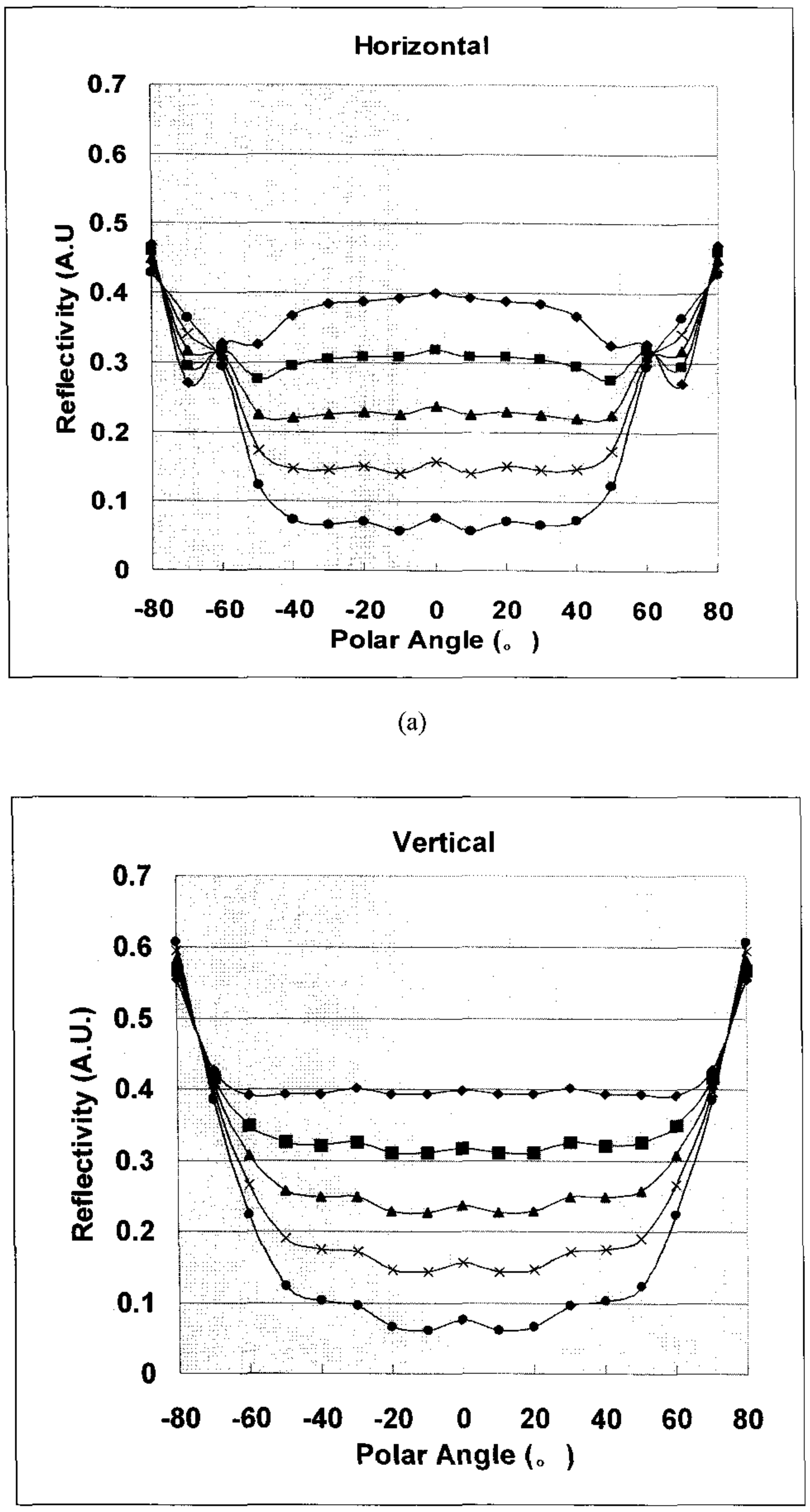


Fig. 4. Cell structures of normaly black reflective system with one polarizer and quarter wave film with state of polarization in each pass.



(a)

(b)

Fig. 5. The simulated results of the viewing angle characteristics using the one polarizer with quarter wave plate.

5. Summary

The FFS display, which has a concept of new pixel electrode discarding conventional interdigital electrode used in conventional IPS display, exhibits high transmittance, wide-viewing-angle, and low crosstalk. In this paper, the overall characteristics of the FFS mode are reviewed. Also, an application of the FFS mode to reflective system is possible, and reflective FFS mode shows wide viewing angle and low driving voltage for one polarizer system with quarter wave film.

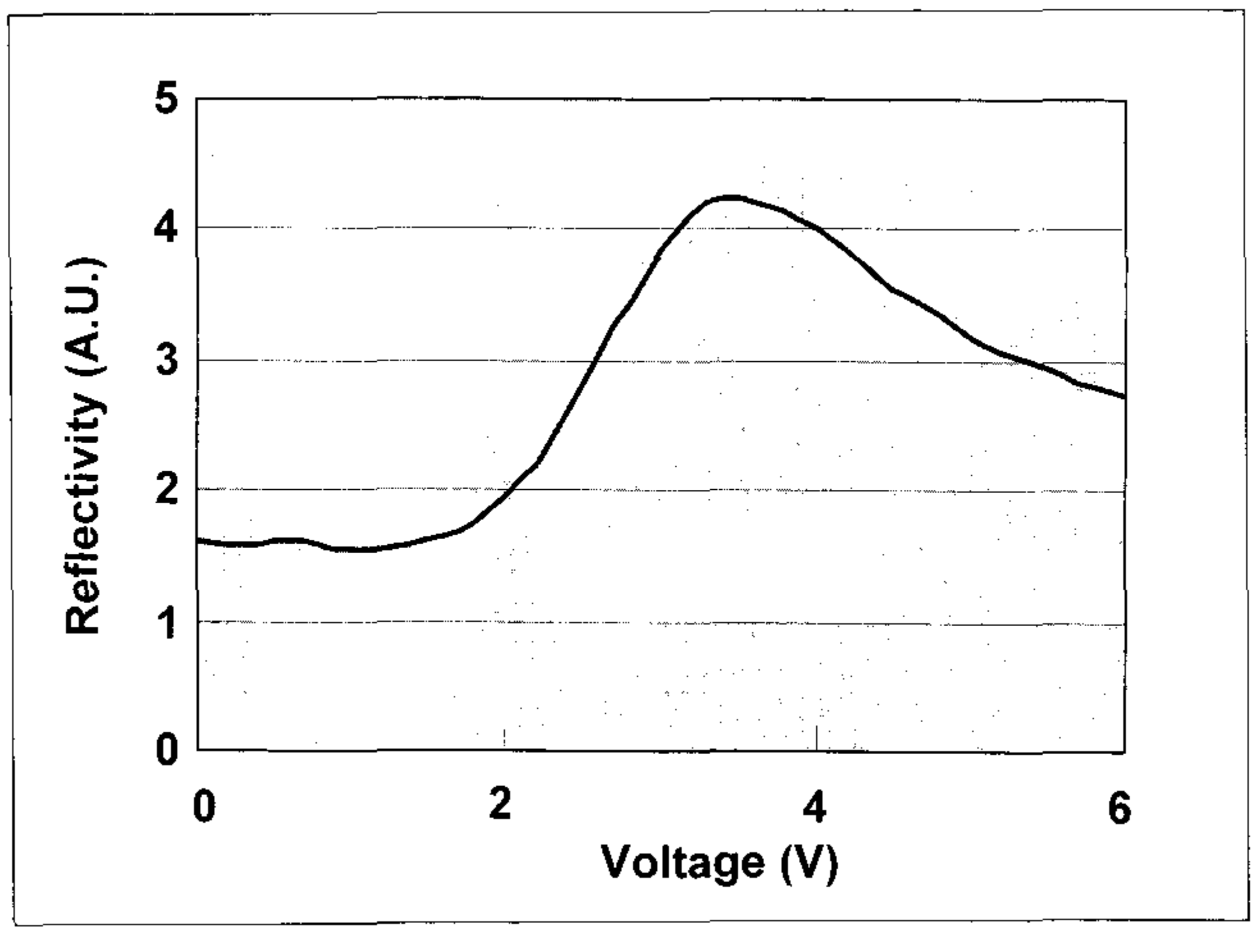


Fig. 6. The voltage dependent reflectivity curve of the reflective device.

References

[1] S. H. Lee, S. L. Lee and H. Y. Kim, Proceeding of the 18th International Display Research Conference (Society for Information Display and the Korean Physical Society, Seoul), p. 371, 1998.

[2] S. H. Lee, S. L. Lee and H. Y. Kim, Appl. Phys. Lett, vol. 73, no. 20, p. 2881, 1998.

[3] S. H. Lee, S. L. Lee, H. Y. Kim and T. Y. Eom, Digest of Technical papers of 1999 Society for Information Display International Symposium (Society for Information Display, San Jose), p. 202, 1999.

[4] S. H. Lee, H. Y. Kim and S. L. Lee, Proceedings of the 6th International Display workshops (Society for Information Display and The Institute of Image Information and Television Engineers of Japan, Sendai), p. 191, 1999.

[5] S. H. Lee, S. L. Lee, H. Y. Kim and T. Y. Eom, J. Kor. Phys. Soc., vol. 35 S1111, 1999.

[6] M. Oh-e, M. Ohta, S. Aratani and K. Kondo, Proceedings of the 15th International Display Research Conference (Society for Information Display and the Institute of Television Engineers of Japan, Hamamatsu), p. 577, 1995.

[7] H. Asuma, *et al.*, Proceedings of the 4th International Display workshops (Society for Information Display and The Institute of Image Information and Television Engineers of Japan, Nagoya), p.167, 1997.

[8] H. Y. Kim, T. Y. Eom, D. H. Suh and S. H. Lee, LCMD '99, p. 107, 1999.