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

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Abstract

Fringe-field switching (FFS) technology exhibiting a high image quality has been developed. In this paper, one pixel concept, manufacturing process, materials, and electro-optic characteristics of FFS mode comparing with conventional in-plane switching mode, and its possible application to reflective type will be discussed.

1. Introduction

Recently, the market of liquid crystal display (LCD) is fast growing in liquid crystal TV as well as monitors. In order to accelerate the replacement of CRT to LCD in monitor 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] showing unique electro-optic characteristics nevertheless the liquid crystal (LC) director rotates in-plane like conventional IPS mode.[2] 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 that the results from others are being reported. In this paper, overall characteristics of the FFS mode and possible application to reflective LCD will be reviewed.

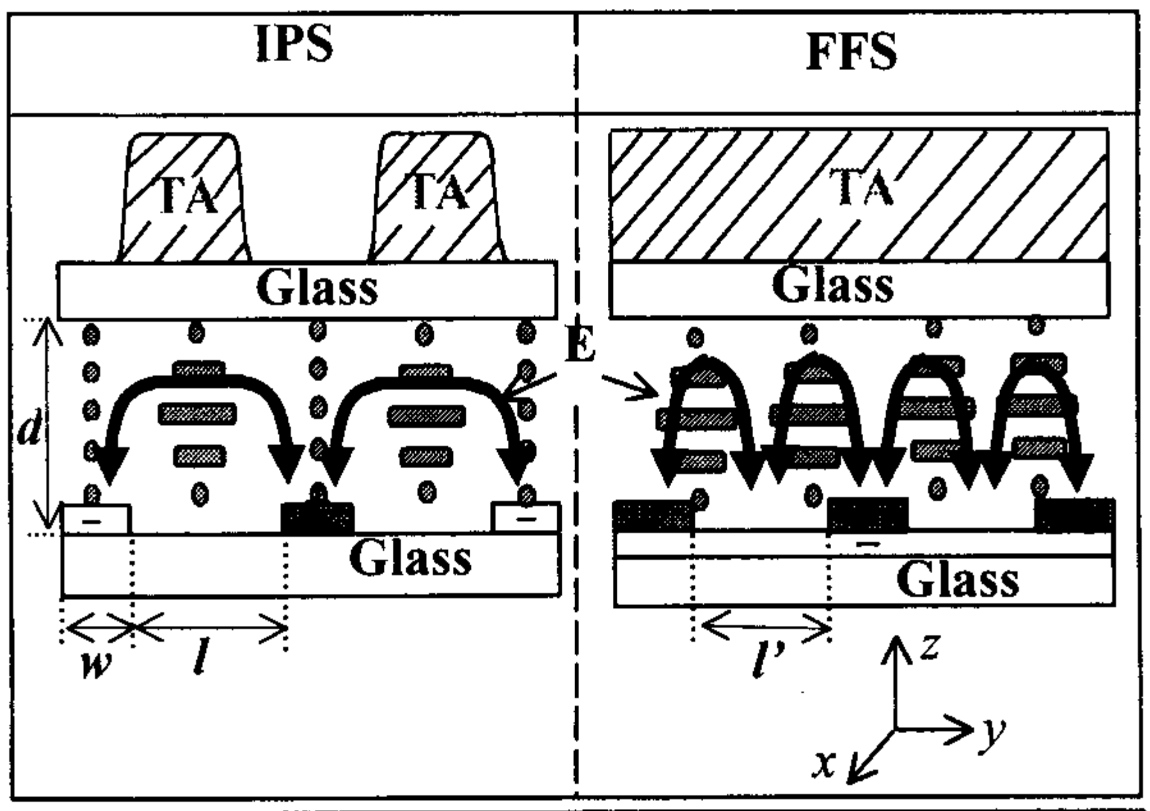
2. Characteristics of the FFS mode

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 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 distance between pixel and common electrodes 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 field, fringe field lines with vertical and horizontal component is 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. In addition, it is much larger than that of the IPS mode. In the cell structure, the liquid crystal molecules are homogeneously aligned under crossed polarizers in the off state so that it appears black. With bias voltage, the fringe-field drives LC director to rotate above whole electrodes, giving rise to 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 though the ITO is not necessary for color filter side, which is only demerit of the FFS mode. 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. Further, the thickness of ITOs is only few hundred Å, so good alignment of liquid crystal molecules with homogeneous alignment layers is obtained without planarization of array substrate.



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

Fig. 1. Features of the IPS and the FFS modes.

2.3 Materials

-Color Filter

In the IPS mode, the resin black matrix (BM), that is, high specific resistance material, is required in order 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 of vertical between data line and BM direction is stronger than that of between electrodes. Consequently Cr BM disturbs in-plane field between electrodes, causing operating voltage up.[3] However, in the FFS mode the distance does not exist between pixel and common electrodes, that is, the field strength caused by Cr BM of upper substrate does not affect the field distribution in modulated area.[4] We have checked voltages at which transmittance changes by 10%, 50%, 90% for both cases and the results are almost same as shown below.

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

When Cr BM is used, the depth difference on overlapped area between color resin and BM and LC modulated area is minimized. This enhances good alignment of LC molecules. This is another advantage of the FFS mode.

- Liquid Crystal

In the FFS mode, both positive and negative dielectric anisotropy of LC can be used. When positive LC is used, the LC director tilts up along fringe field line instead of rotation so that the degree of twist above center of electrodes is low, resulting in low transmittance. However, when negative LC is used, the rotation of LC director occurs in whole area, resulting in high transmittance. In the IPS mode, the light efficiency for both types of LCs is same. Another distinct difference between the IPS and the FFS modes is voltage-dependent transmittance curves depending on rubbing directions. Fig. 2 shows that the transmittance is decreasing with increasing rubbing direction with respect to field direction for positive LC case, whereas it remains same for negative LC one. Since dielectric torque and elastic force between neighboring molecules rotate the LC director in the FFS mode, the tilt-up molecules near the edge of electrodes cause less twist deformation above electrodes as rubbing direction increases for positive LC.

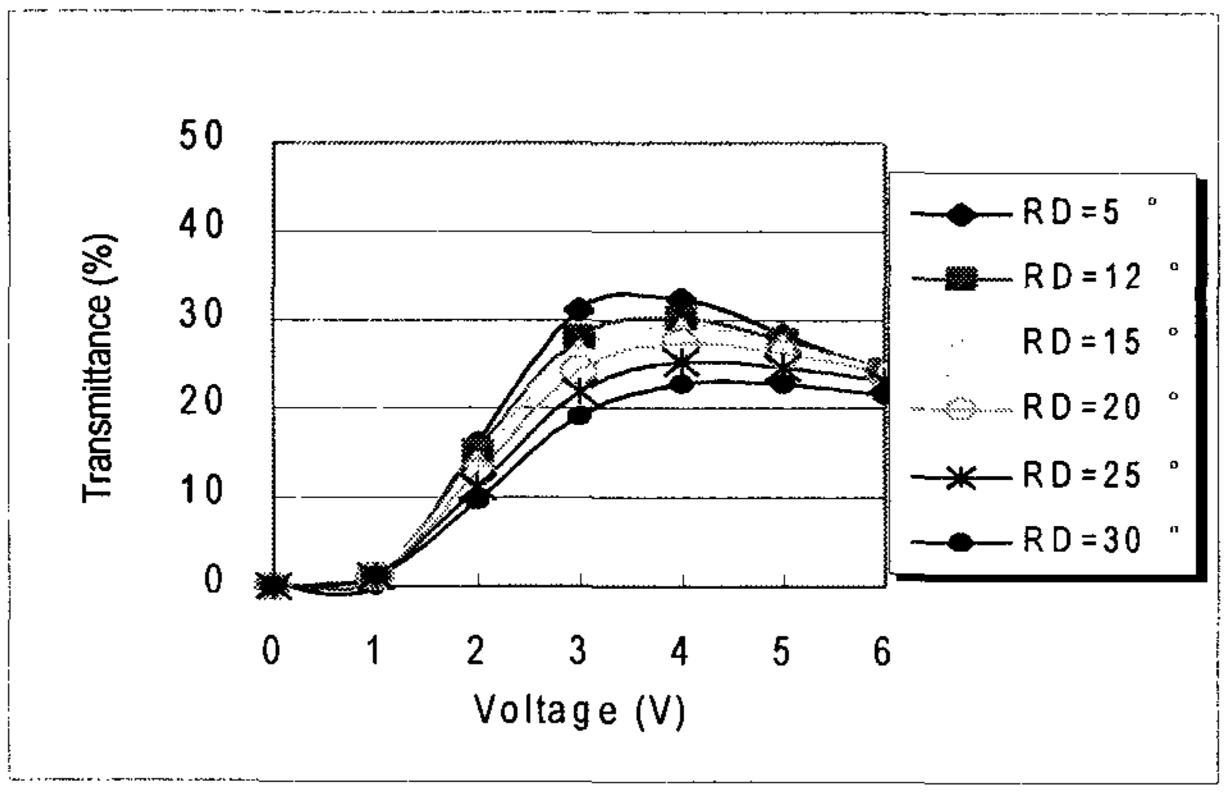


Fig. 2. Voltage-dependent transmission curves as a function of rubbing directions for positive LC.

3. Electro-optic characteristics of the FFS mode

- Crosstalk

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

- 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 is alternating in the FFS mode. This effect improves uniformity in brightness and results in less yellowish and bluish color shift than that of the IPS cell. The contrast ratio greater than 10 exists over 80° in all directions.

3. Application of the FFS mode to Reflective LCD (R-FFS)

The concept of in-plane orientation of LC director can be applied to reflective LCD, owing to high transmittance characteristic of the FFS mode. Several types of cell structures with one or two polarizers and with or without compensation films are possible. Fig. 3 shows principle of operation for normally black mode with one polarizer (P) and λ /4 plate. In the off- state, the optic axis of LC director and P is coincident while having 45° between P and 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

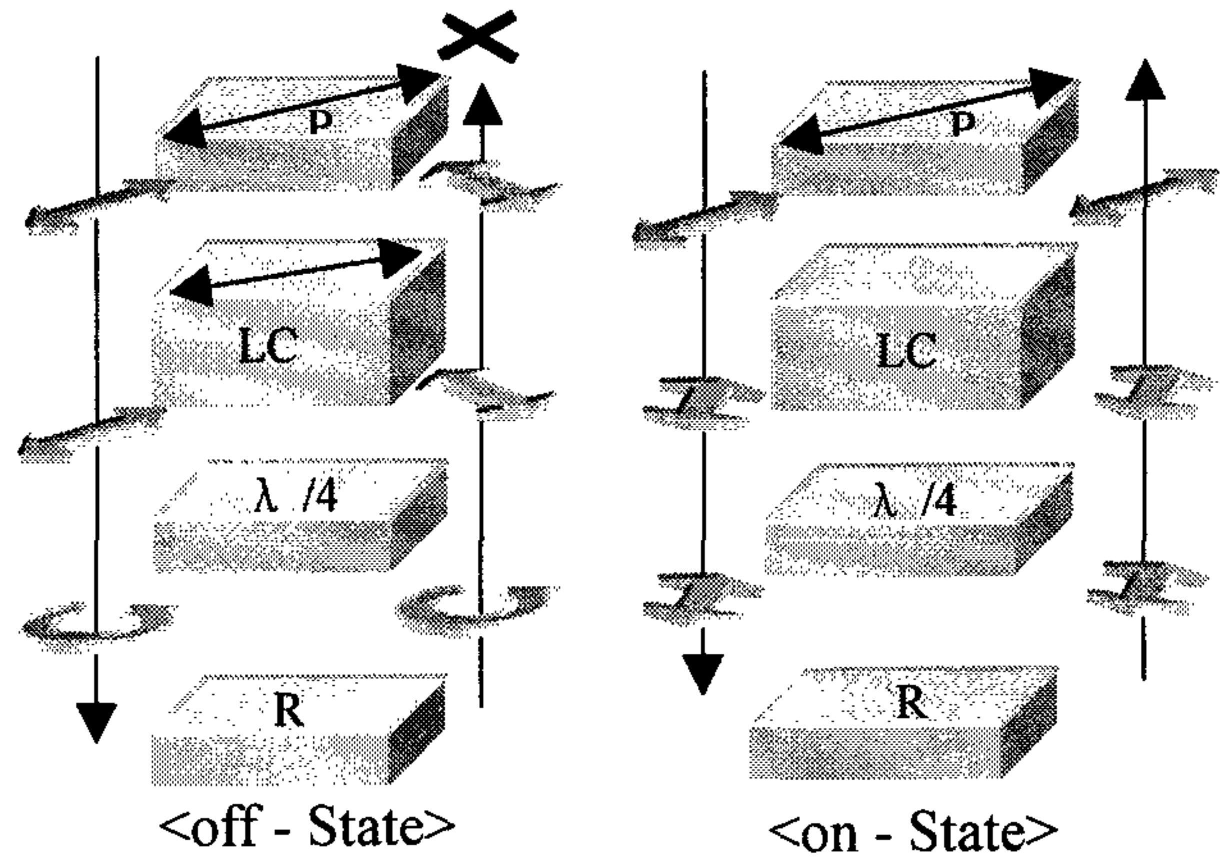


Fig. 3 Operational principle of reflective LCD with λ /4 plate.

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. Now, 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. R-FFS mode shows intrinsically no grey scale inversion over wide range.

4..Summary

The FFS display exhibits high transmittance, wide-viewing-angle, and low crosstalk. Even further, an application to reflective system is possible, and color shift free with fast response time will be published later.

References

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