Fringe-Field Switching Transflective Liquid Crystal Displays

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Abstract

This paper investgates the transflective liquid crystal displays (LCDs) associated with fringe-field switching (FFS) mode to achieve high image quality. In the past, several cell structures were used to fabricate transflective FFS LCDs. Their structures and characteristics are carefully examined to find their merits and demerits. In addition, we attempt to optimize cell parameters to achieve a single driving circuit.

Keywords : transflective display, fringe-field switching, high image quality

1. Introduction

Recently, transflective liquid crystal displays (LCDs) are being more widely commercialized because they can be used both indoor and outdoor with relatively lower power consumption than that in transmissive display [1-3]. At present, the transflective displays use twisted (TN) and homogenous cell (named ECB) with compensation film [4]. However, in both TN and ECB modes, the LC director tilts up in one direction along the vertical field direction, hence restricting the viewing angle in the transmissive region. In fringe–field switching (FFS) mode, homogenously aligned LC reacts to applied voltage and rotates in one direction, while maintaining to be almost parallel to the substrate. This, enhances transmission of as well as widen the viewing angle. Recently, many experiments and computer simulations on electro-optical characteristics of the transmissive [5-7] and reflective [8] FFS LCD have been carried out. Further, many results on the FFS transflective displays such as homogenous cells with compensation film driven by fringe-electric field with dual cell gap [9], single cell gap with multi-driving circuit [10] as well as dual orientation [11] have been reported.

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In the paper, the structures and characteristics of these are carefully examined in order to identify their merits and dimerits. In each case, cell conditions were optimized to achieve single gap, single driving, single orientation and wide viewing angle transflective FFS liquid crystal display which is easy to fabricate.

2. Cell Structure of FFS Transflective Display and Their Characteristics

2.1 Dual gap Transflective FFS Display

Fig. 1 shows calculated voltage-dependent light efficiency in the dual gap tansflective display using a LC with negative dielectric anisotropy (-LC). High light efficiency of 98% was achieved in both reflective and transmissive parts. Operation voltages for reflective and transmissive parts are 5.7 and 4.7V, respectively. The difference between reflectance and transmittance curves is due to the fact that the cell gap of reflective part is twice that of transmissive part. Moreover, light efficiency is reduced when cell gap is less than 2um in FFS mode with homogeneously aligned LC [12].

Fig. 2 shows iso-contrast curves in the T and R regions at an incident wavelength of 550 nm. In this cell, the region ($R_{CR>5}$) in which the contrast ratio (CR) is larger than 5 exists at a polar angle of more than 50° in all directions in both the T and R regions.

The merits of the dual gap transflective are high transmittance and wide viewing angle. The demerits of the

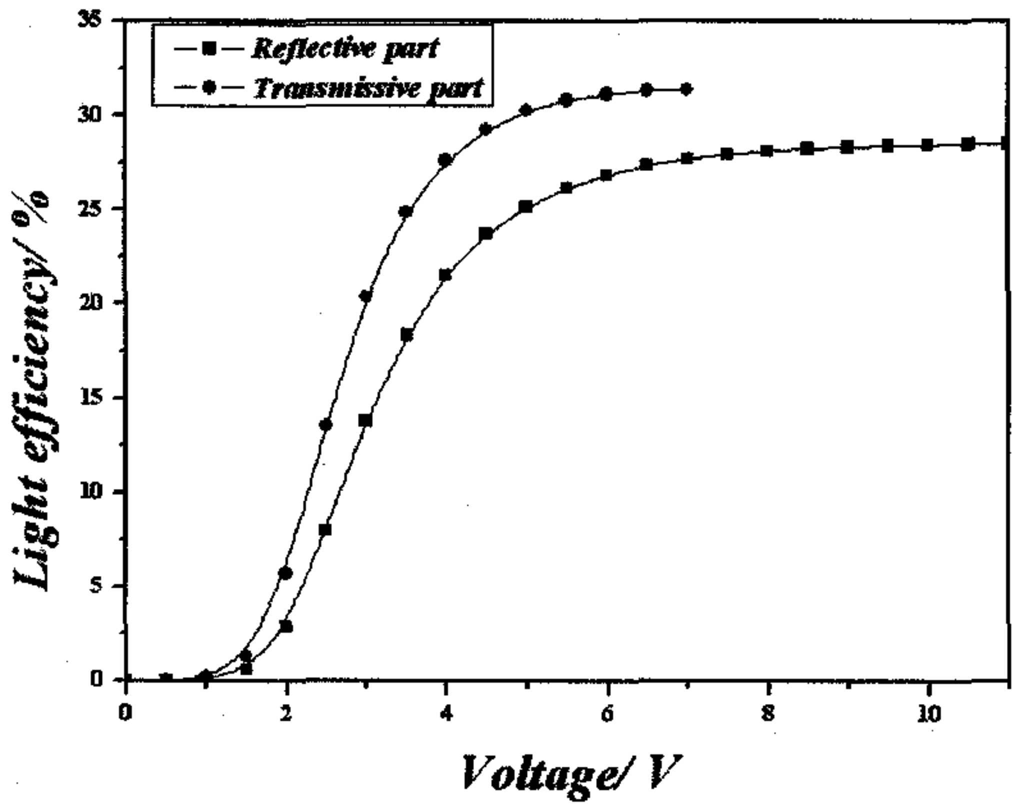


Fig. 1. Voltage-dependent light efficiency in the dual gap tansflective display.

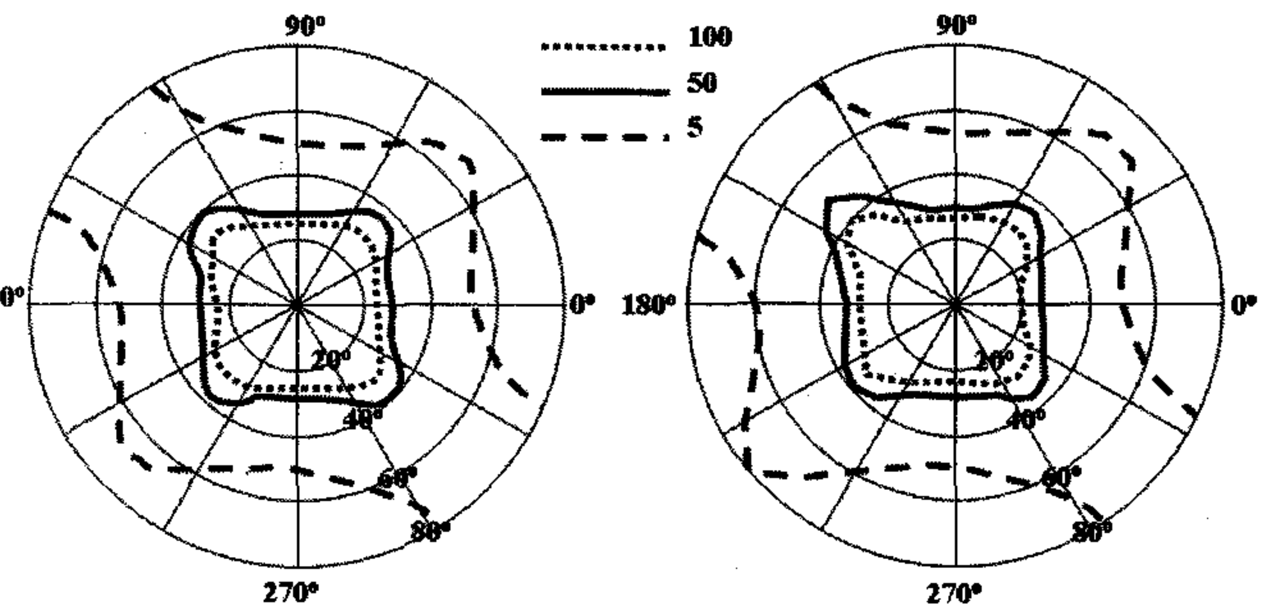


Fig. 2. Iso-contrast contour at an incident wavelength of 550 nm in the dual gap transflective display: (a) R-part, (b) T-part.

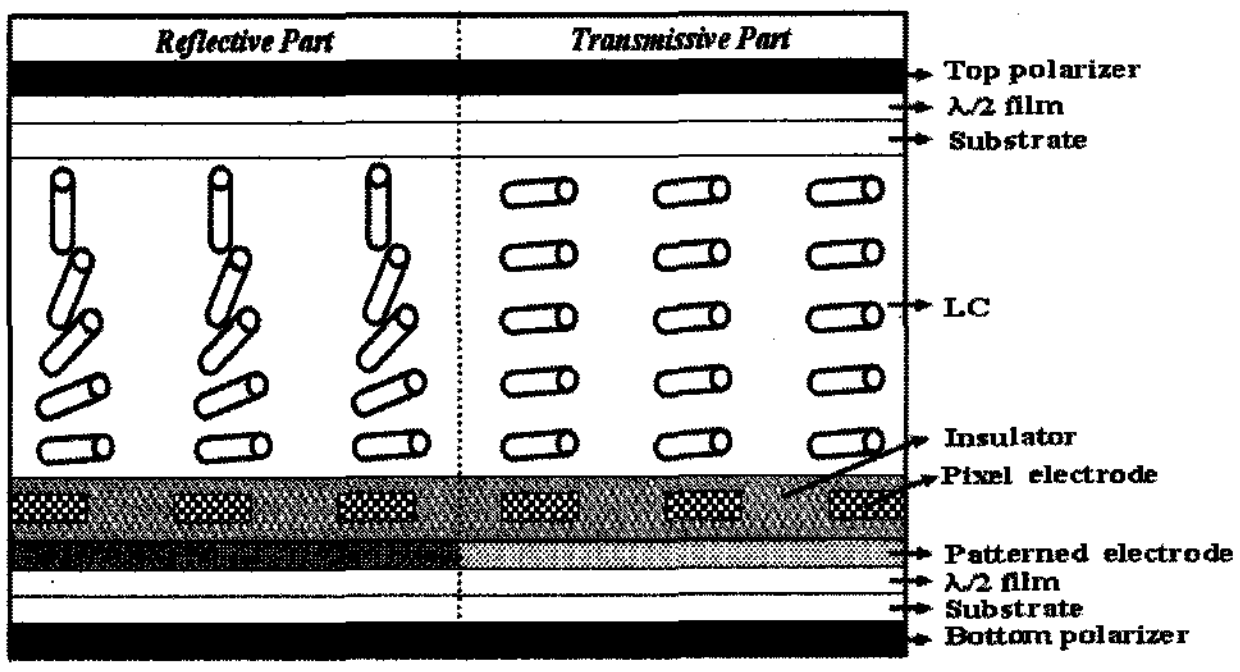
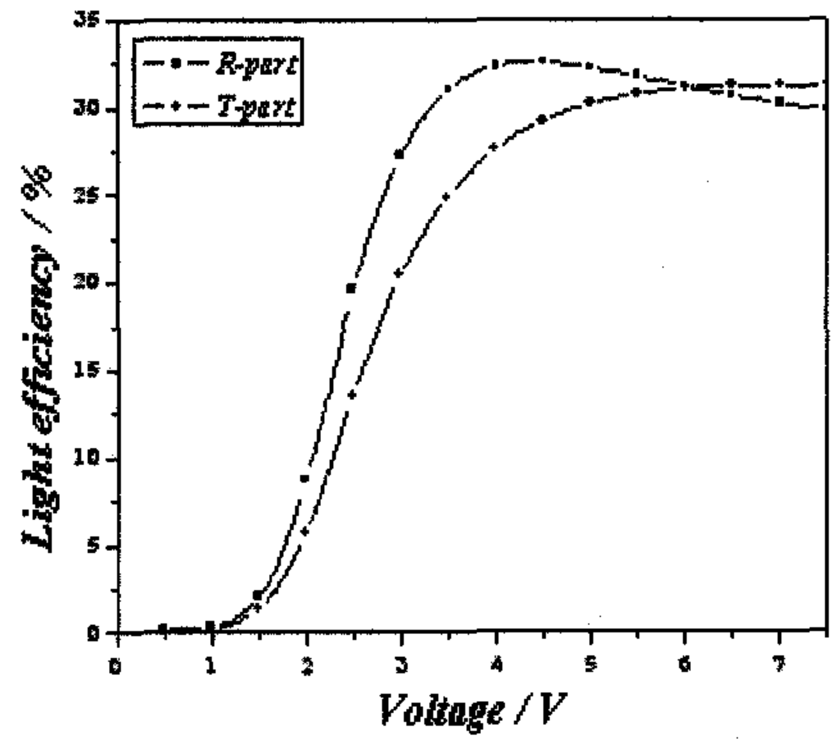
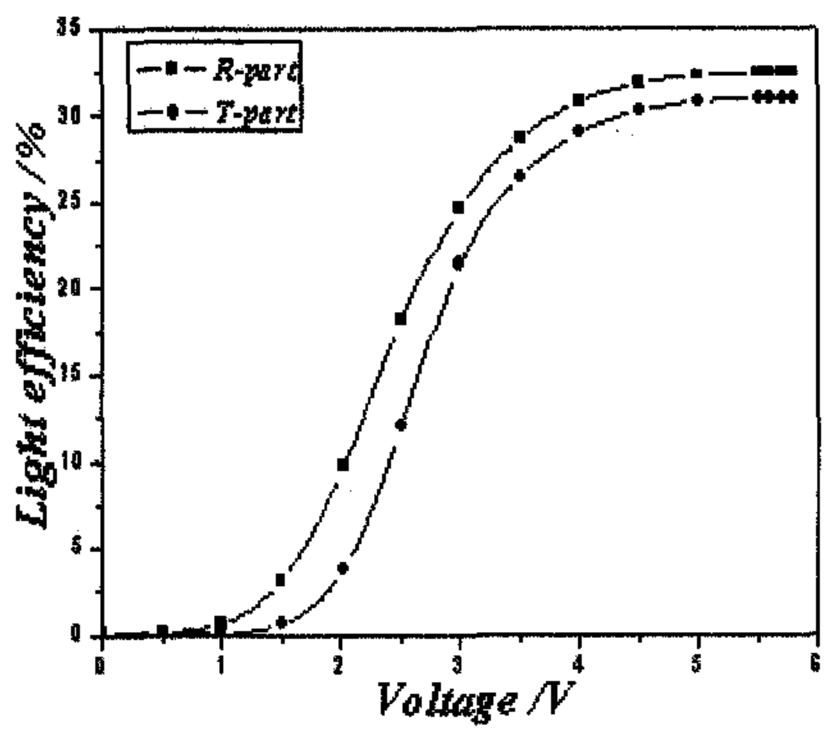


Fig. 3. Schematic cell structure of the dual orientation transflective display.



(a)



(b)

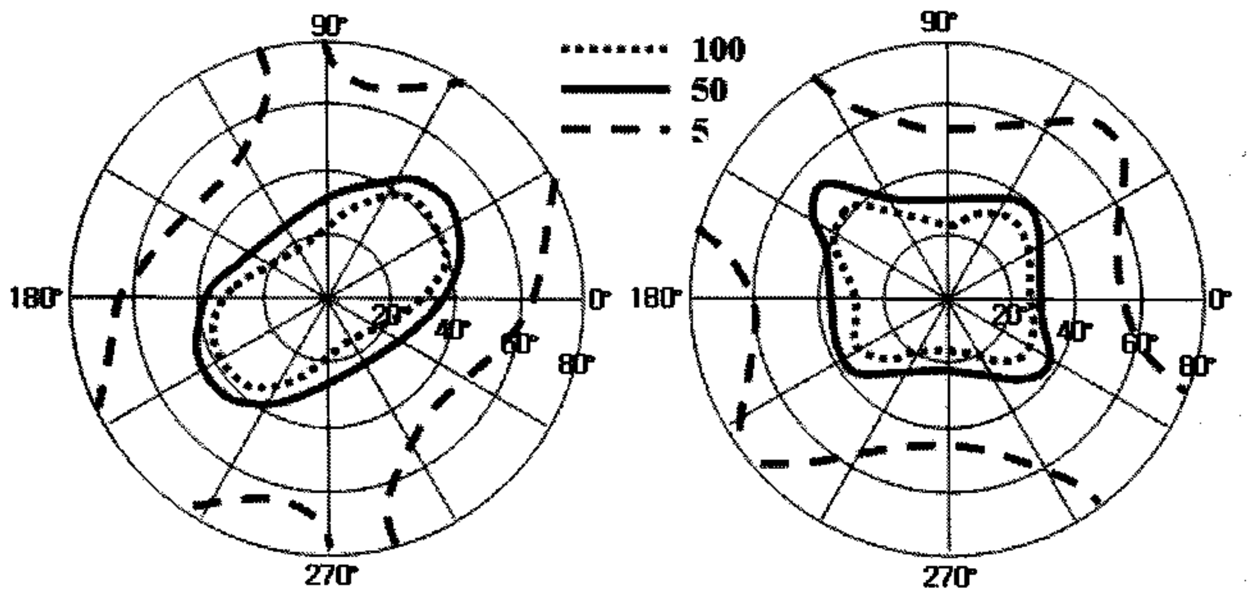
Fig. 4. Voltage-dependent light efficiency in the dual orientation transflective display: (a) 12° rubbing angle at R-and T-part (b) 20° rubbing angle at R-part and 5° rubbing angle at T-part.

dual gap transflective is high sensitivity of a dark state and dual cell gap, such that complex manufacturing process and unwanted LC alignment exists in the region between R- and T- parts.

2.2 Dual Orientation Transflective FFS Display

Fig. 3 shows a schematic cell structure of the dual orientation transflective display [11]. In the R region, the LC has a hybrid alignment while it has a homogeneous alignment in the T region. The LC on the bottom substrate has homogeneous alignment in both regions while the LC has dual alignment on the top substrate. This means that, the effective cell retardation value in the R region equals about half of the T region. Owing to this, a single gap transflective display is realized.

Fig. 4 (a) shows calculated voltage-dependent light efficiency in the dual orientation transflective display when the wavelength of an incident light is 550nm, using the -LC. Here, the rubbing angle is 12° for both cases. In this cell, the R region shows a slightly higher light efficiency than that in the T region because the optimal cell retardation value for maximal light efficiency is slightly. Fig. 4 (b) shows calculated voltage-dependent light efficiency in the 20° rubbing angle at R-part and 5° rubbing angle at T-part



(a) (b)

Fig. 5. Iso-contrast contour at an incident wavelength of 550 nm in the dual orientation transflective display: (a) R-part, (b) T-part.

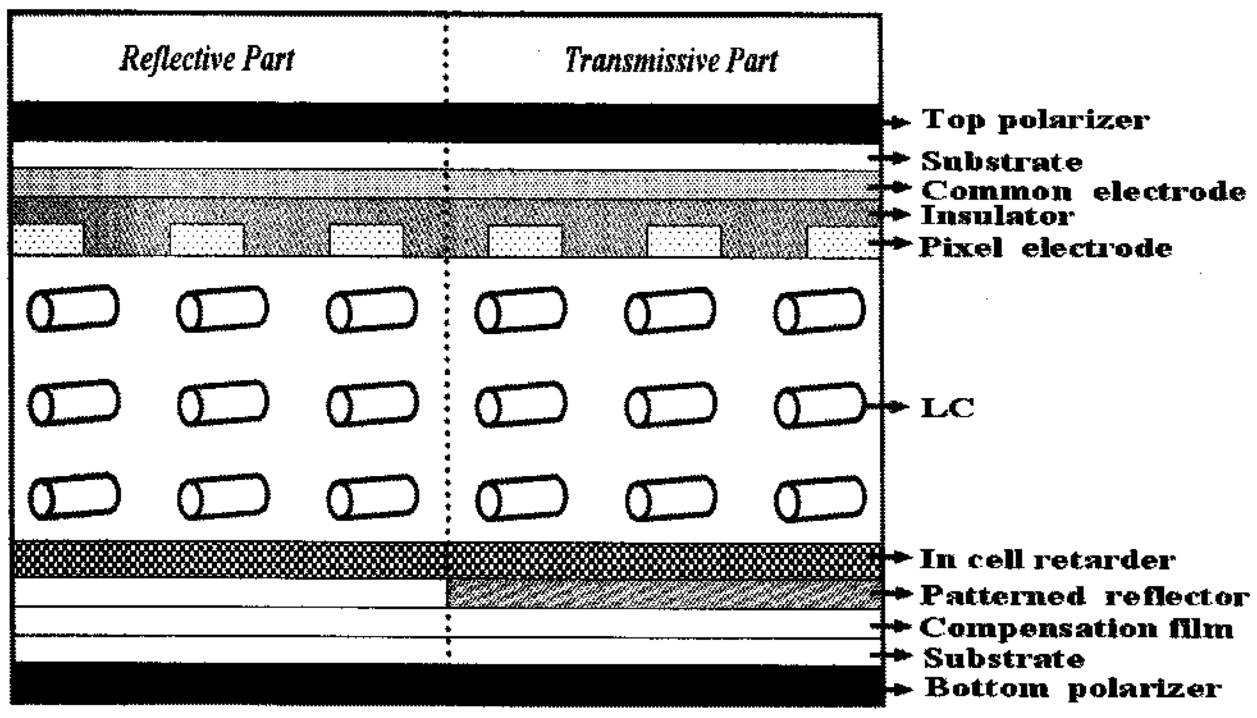


Fig. 6. Schematic cell structure of the single gap transflective display.

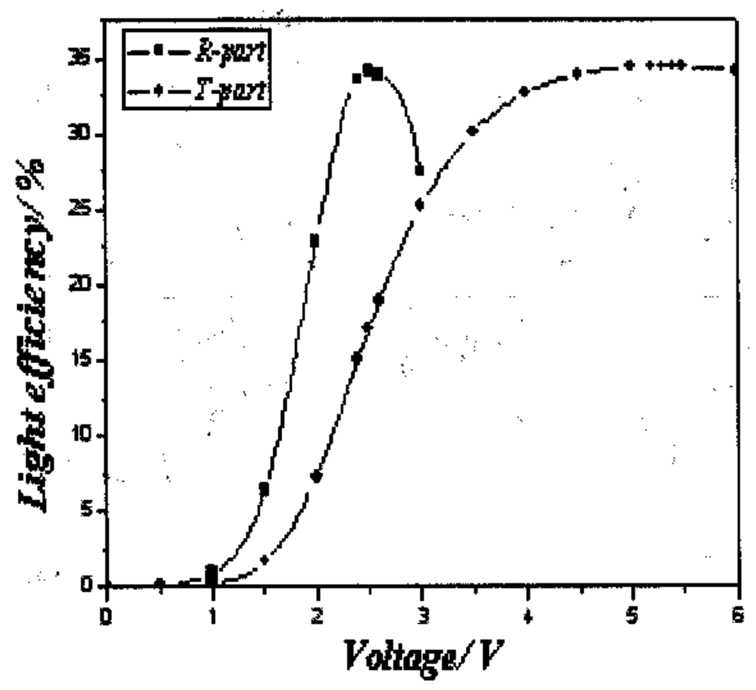
when the wavelength of an incident light is 550nm, which narrows the difference between two curves. Further optimization of voltage-dependent T and R curves is required.

Fig. 5 shows iso-contrast curves is the T and R regions at an incident wavelength of 550 nm in the dual orientation transflective display. In this cell, the $R_{CR>5}$ exists at a polar angle of more than 50° in all directions in both the T and R regions.

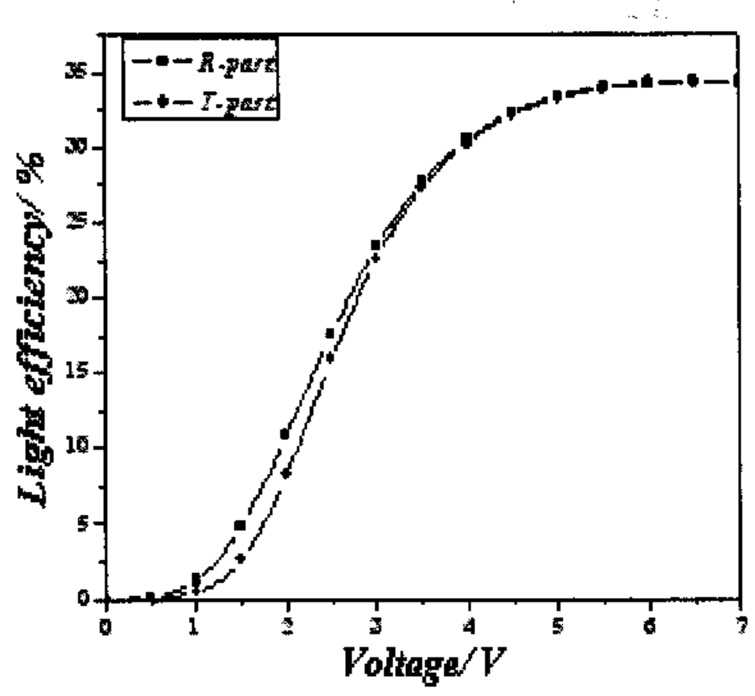
The merit of the dual orientation transflective display is that the device can have a high single cell gap with wide viewing angle. However, the demerit is that two domains are formed and the high sensitivity of a dark state to cell retardation.

2.3 Single Cell Gap Transflective FFS Display

Fig. 6 shows a schematic cell structure of the single gap transflective display [13-14]. In the device, the pixel and counter electrodes exist only on the top substrate. The



(a)



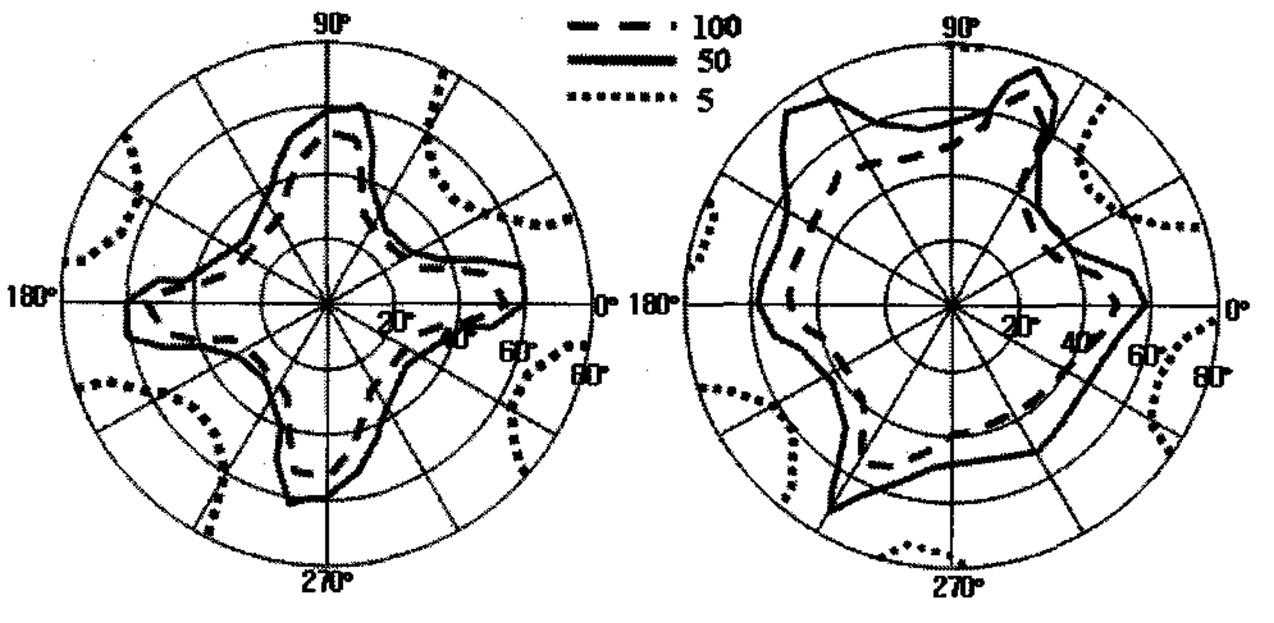
(b)

Fig. 7. Voltage-dependent light efficiency in the single gap tansflective display when using negative LC: (a) 12° rubbing angle at both R-and T-part (b) 55° rubbing angle at R-part and 20° rubbing angle at T-part.

in-cell retarder with a quarter-wave plate(λ/4) exists above the patterned reflector. One compensation film with λ/4 exists below bottom substrate. Two polarizers are crossed to each other and an optic axis of the LC coincides with one of the polarizer axes. With this structure, the existence of the in-cell retarder does not increase an operating voltage (V_{op}).

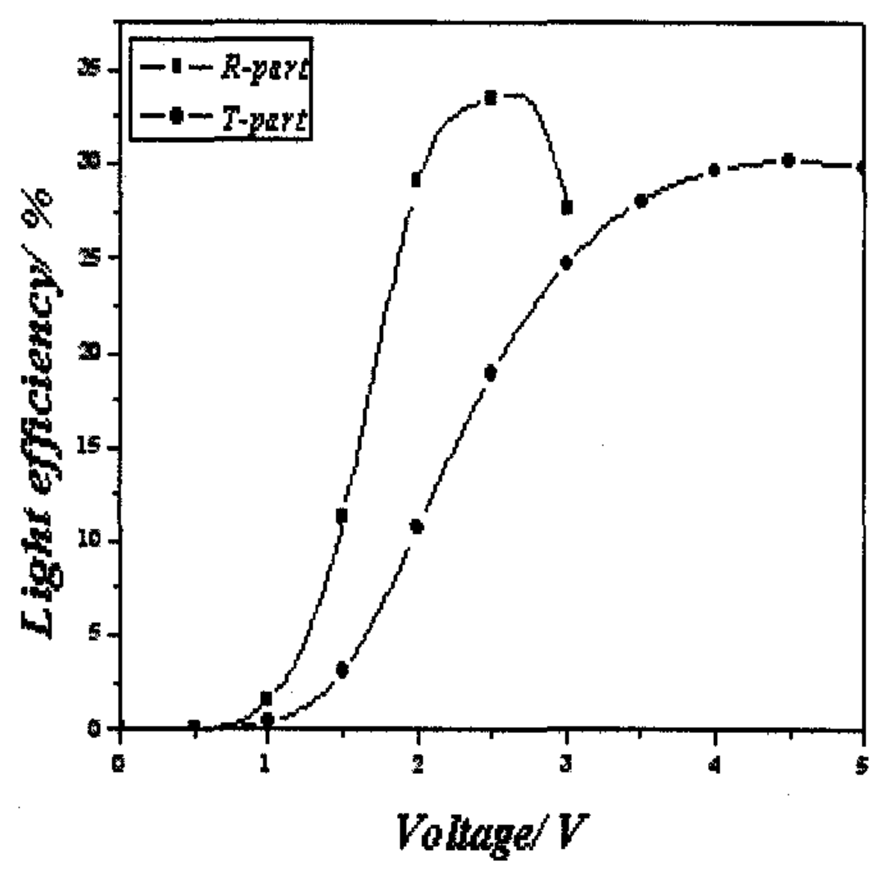
Fig. 7(a) shows voltage-dependent light efficiency in the single gap transflective display when using the -LC ($\Delta\varepsilon$ = -4.0, rubbing angle 12°). Unfortunately, the two curves do not coincide with each other. Fig. 7(b) shows the calculated voltage-dependent light efficiency in the 55° rubbing angle at R-part and 20° rubbing angle at T-part. From this figure, it can be seen that a single driving circuit can control the applied voltage in both the reflective and transmissive region.

Fig. 8 shows iso-contrast contour at an incident wavelength of 550 nm in the single gap transflective display. In the *R* part, the $R_{CR>5}$ exists at about 50° of polar angle in all

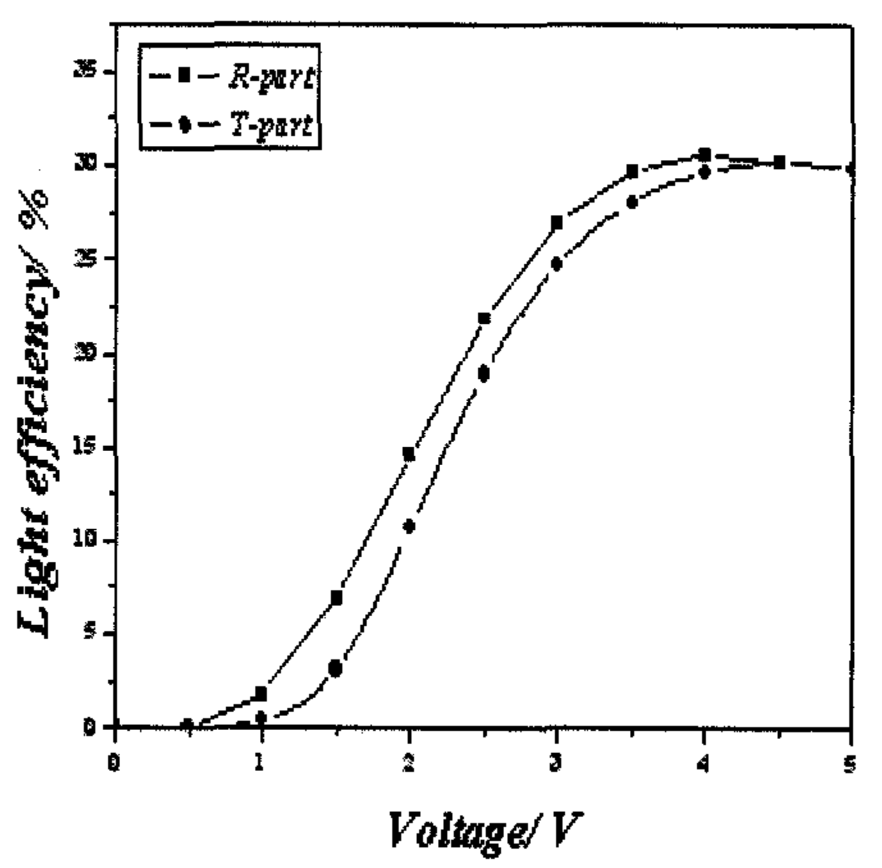


(a) (b)

Fig. 8. Iso-contrast contour at an incident wavelength of 550 nm in the single gap transflective display using negative LC: (a) R-part, (b) T-part.



(a)



(b)

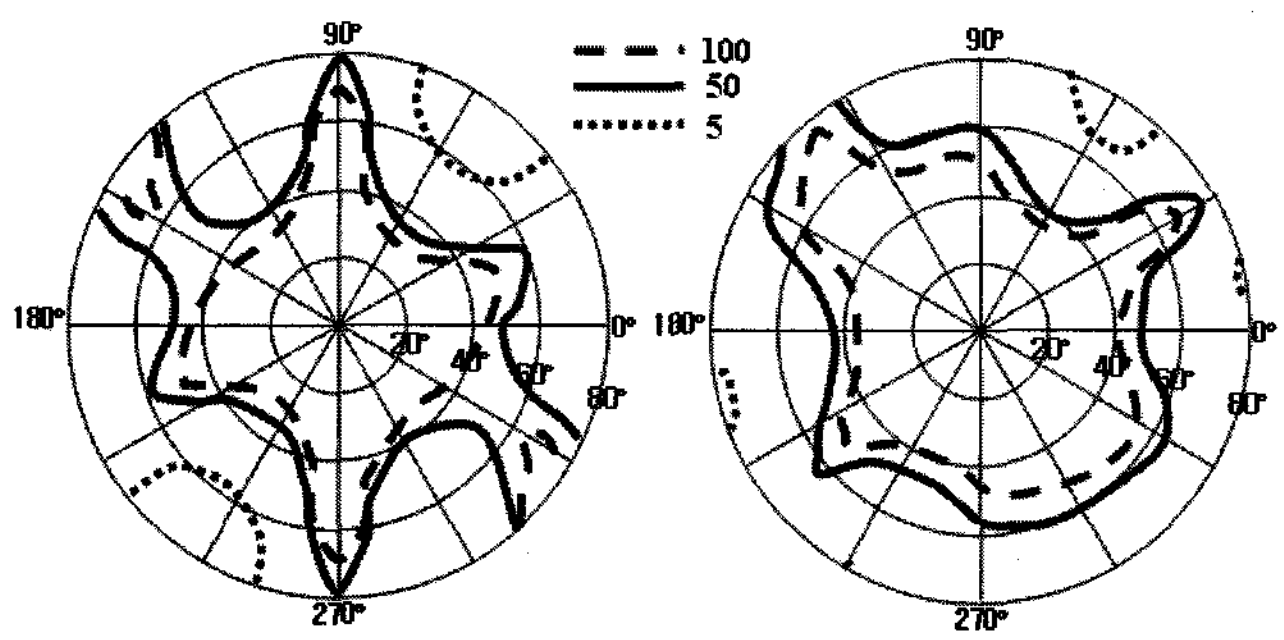
Fig. 9. Voltage-dependent light efficiency in the single gap transflective display when using positive LC: (a) 80° rubbing angle at R-and T-part (b) 45° rubbing angle at R-part and 80° rubbing angle at T-part.

directions, except in certain diagonal directions, where it exists at a polar angel greater than 80°. In the *T* area, the $R_{CR>5}$ that is larger than 10 exists over 60° of polar angle in all directions.

We also calculated a voltage-dependent reflectance and transmittance using the LC (+LC) with positive dielectric anisotropy ($\Delta\varepsilon$ = 7.4, rubbing angle 80°), as shown in Fig. 9(a). It can be seen from this figure that, the two curves do not coincide with each other. Fig. 9(b) shows calculated voltage-dependent light efficiency in the 45° rubbing angle at R-part and 80° rubbing angle at T-part when using the +LC. In this way, the difference in two curves is reduced.

Fig. 10 shows iso-contrast contour at an incident wavelength of 550 nm in the single gap transflective display using positive LC. In the *R* part, the $R_{CR>5}$ was larger than 5 exists at a polar angle of about 60° polar angle in all directions, except in certain diagonal directions, where it exists at a polar angle greater than 80°. In the *T* area, $R_{CR>5}$ exists at a polar angle of greater than 70° in all directions. In trasmissive and reflective parts, polar angle of [with the +LC] is about 10° higher than that with the -LC.

The merit of the single gap transflective is that the dark state is not influenced by the cell retardation value. This is not the case in other transflective cases with single cell gap and high image quality. However, the demerit is that it requires an additional process to coat the in-cell retarder.



(a) (b)

Fig. 10. Iso-contrast contour at an incident wavelength of 550 nm in the single gap tansflective display using positive LC: (a) R-part, (b) T-part.

3. Implications

This study is the first research to propose single cell gap and single driving circuit with wide viewing angle transflective display using fringe-field. The device is expected to be applicable to small and medium-sized transflective display.

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