# P-190: Wide-Band Transflective Liquid Crystal Display in a Patterned Vertically Aligned Mode with a Single Cell Gap

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## Abstract

*We propose optical configuration for wide-band characteristics in transflective liquid crystal display with a single cell gap at patterned vertically aligned mode. Difference of the optical path between transmissive and reflective parts is compensated by designing the electrode structure and adopting two retardation films which show wide band characteristics calculated from mirror imaging method.*

## 1. Introduction

Transflective liquid crystal displays (LCDs) have been constantly studied for mobile device applications, digital cameras, and personal digital assistants due to their portability, their low power consumption, and good display performance under indoor and outdoor environments [1, 2, 3]. Many kinds of structures, such as multi-cell gap and dual LC modes have been suggested to compensate the optical path difference between transmissive (T) part and reflective (R) part [4, 5]. Multi-cell gap has a merit that can get single gamma characteristic. However, manufacturing processes are very difficult to produce multi-cell gap since the cell gap between the transmissive and reflective parts is different. Also it has mismatch of the response time between transmissive part and reflective part. Transflective LCD with dual mode has relatively easy manufacturing process due to single-cell gap, and almost same response time. However, it is not easy to obtain single gamma characteristics due to different electro-optic characteristics of two modes. Consequently, complex driving circuits are needed, to adjust electro-optic characteristics of two modes by controlling electrically LC director behavior related to optical characteristic [6, 7].

In our previous work [8, 9], we proposed a transflective LCD structure in a patterned vertically aligned (PVA) mode with a single cell gap and single LC mode. At that work, optical path difference is compensated by designing the electrode structures and same optical configurations are realized over the whole display regions. However, all kinds of electro-optic characteristics are very good at only specific wavelength.

In this work, we propose improved wide-band characteristics of transflective LCD with a single cell gap in PVA mode. New electrode structures are designed to compensate the different optical paths between transmissive and reflective parts, and wide-band characteristics are realized by adopting two retardation films using mirror image method. As results, we got very good wide-band characteristics of simulated results at transmissive part and reflective part.

## 2. Cell structure and Operation Principle

The proposed structure is shown in Fig. 1. It is composed of two crossed polarizers, two $\lambda/2$ films, two $\lambda/4$ films, and LC layer. We used the inner retardation film with a retardation value of $\lambda/4$ that is made of liquid crystal polymer (LCP: RMS-03-001C, Merck) [10, 11]. The used LC mode was PVA mode with chevron shape and the maximum value of filed-induced LC retardation was $\lambda/2$.

For the dark state of the reflective part, the optic axes of $\lambda/2$ and $\lambda/4$ retardation films are positioned in $\alpha_1 = \pm 15°$ and $\alpha_2 = \pm 75°$, respectively, with respect to top polarizer by using Stokes parameters. Under this condition, the lights of almost all wavelengths in visible range could be circularly polarized light in front of reflector and could get the linearly polarized light rotated by 90° finally in front of top polarizer after returning.

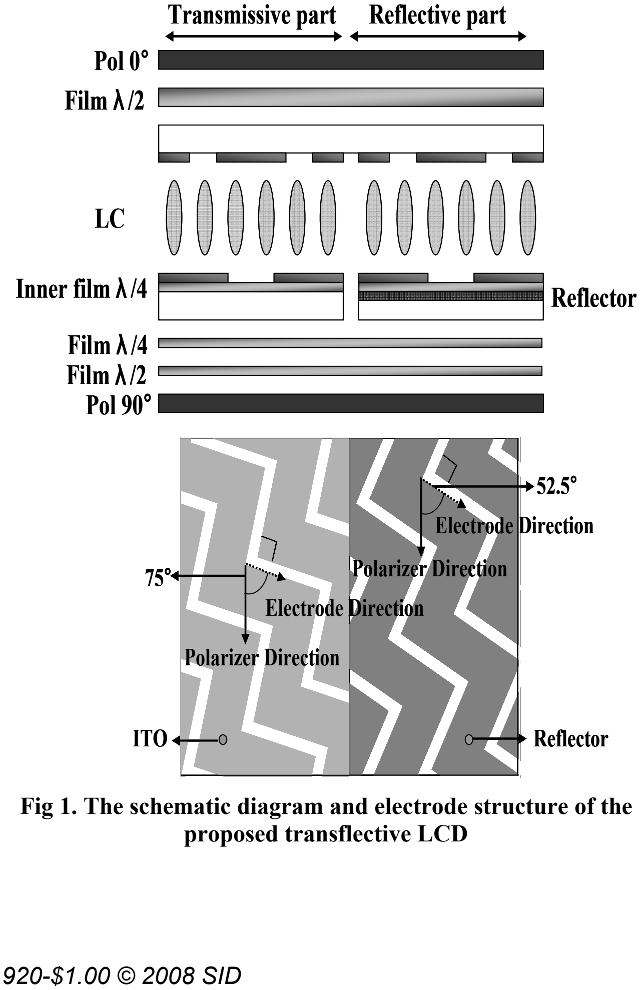

**Fig 1. The schematic diagram and electrode structure of the proposed transflective LCD**

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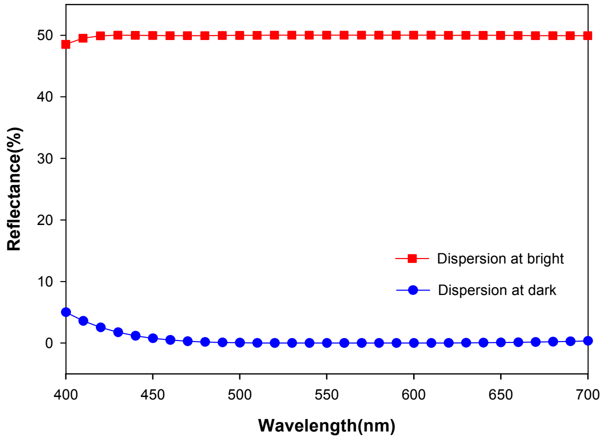
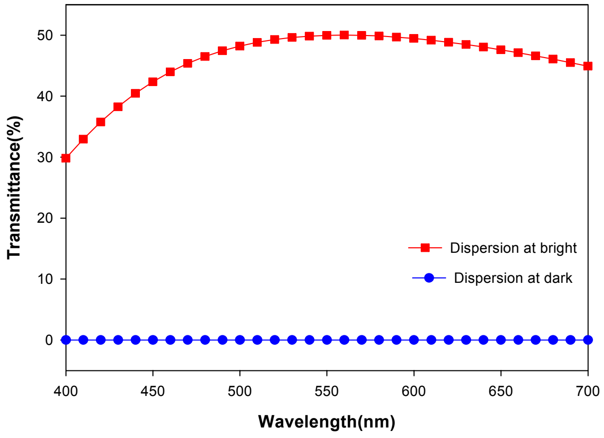
So, that is almost blocked by the top polarizer and we could get the dark state for visible light region as shown in below line of Fig. 2 (a).

For the bright state of the reflective part, the retardation of LC layer was set up as Δ nd = 0.36. To get maximum reflectance under a given conditions, we calculated numerically. As a result, when the optic axes of LC layer are 52.5˚ with respect to polarizer, we can obtain maximum reflectance. The dispersion at the bright state is excellent at all wavelengths in visible range as shown in above line of Fig. 2 (a).

For the dark state of the transmissive part, λ/2 and λ/4 retardation films between glass substrate and bottom polarizer are used for compensating the fixed two retardation films at reflective regions by using mirror image method. The optic axis of λ/2 film is positioned in 105˚ with respect to the optics axis of top polarizer, to compensate the above λ/2 retardation film having the optic axis of 15˚. As the same approach, the optic axis of λ/4 film is positioned in 165˚ with respect to the optics axis of top polarizer, to compensate the above λ/4 retardation film having the optic axis of 75˚.



(a)



(b)

**Fig. 2. Wavelength dispersion characteristics at the reflective regions and transmisive regions. They show an excellent dispersion at dark and bright states.**

In initial state with homeotropically aligned LC layer, the polarization state of linearly polarized light by the bottom polarizer is not changed after passing though the four retardation films. Finally the linearly polarized lights are blocked by the top polarizer. So, we can realize the optically good wide-band dark state.

For the bright state of the transmissive part, to achieve maximum transmittance under a given several film conditions, we calculated transmittance according to optic axis of LC layer using Poincare sphere. As a result, when the optic axis of LC layer is 75° with respect to the top polarizer, we get maximum transmittance. As another merit, chevron structure with four domains can produce wide viewing angle characteristics with other compensation films in transmissive part. We can obtain the dark state and the bright staes as shown in Fig. 2(b).

## 3. Experiment

The transflective LC cell in a symmetrical transmisive part and reflective part was made by using indium-tin-oxide (ITO) substrate as the electrode. In order to make the chevron shape, ITO electrode patterning was wet-etching-processed by using the positive photo-resist. The electrode width and gap were periodically 50㎛ and 10㎛, respectively. The directions of linear pattern at the chevron electrode are 75° and 165° with the top polarizer at the transmissive part. On the other hand, the directions of linear pattern at the chevron electrode are 52.5° and 142.5° with the top polarizer at the reflective part as described in the calculated results. In this work, LCP was used as the λ/4 retardation film in LC cell, whose ordinary and extraordinary refractive indices are $n_o$=1.529, $n_e$=1.684, respectively. Therefore we can obtain retardation value of λ/4, when thickness of LCP is 0.94㎛. In order to produce the thickness, we mixed LCP and toluene in the ratio 2:1. RN-1744 (Nissan Chemical Ind., Japan) was used as the LCP alignment material. The alignment layer was rubbed to 75° with respect to the top polarizer after baking process and then, mixture of LCP and toluene was coated on the alignment layer under 6000 rpm. The mixture of LCP and toluene was dried at 60℃ for 5min and exposed the UV light of 365㎚, 7.4㎽ under a nitrogen environment for 30min. AL1H659 (JSR CO., Japan) was used as the LC alignment material, to align homeotropically LCs at initial state. The thickness of the LC layer is 3.5 ㎛ and LC material employed is MLC-6610(Merck) of a negative dielectric anisotropy (Δε). The LC injection was carried out at room temperature.

## 4. Results and Discussion

Techwiz LCD (Sanayi System Co., Korea) was used as a commercial simulator to get the electro-optic characteristics by LC director behavior in our proposed transflective mode. The LC parameters for simulation was that cell gap is 3.6㎛, ordinary and extraordinary refractive indices of nematic LC are $n_o$=1.5824 and $n_e$=1.488 respectively, the dielectric anisotropy is Δε =-3.1, the elastic constants are $K_1$ = 14.6x $10^{-12}$ N and $K_3$ =16.5 x $10^{-12}$ N, and the rotational viscosity is γ =148mpA• sec. In the field- off state, since the direction of LC molecules is vertically aligned, the LC layer has no phase retardation and shows the dark state under crossed polarizer. In the field on-state, the direction of LC molecules is tilted along electric filed direction.

By the way, the electro-optic characteristics of the transmissive part and reflective part are mismatched in the gray region. Figure 3 shows EO characteristics of red wavelength. Also there are mismatches in the gary regions of green and blue. So this transflective mode may show inferior image performance resulting from color mismatch between the transmisive part and reflective part. As a typical way to match it, we can use individual circuits at each part. However, use of two thin film transistors (TFT) in one pixel may be unavailable in terms of fabricating process as well as cost. We can solve this problem by decreasing the patterning angle of reflective electrode and changing electrode structure. Figure 4 show EO characteristics at transmissive and reflective parts with electrode structure of 70:5 that mean the ratio between electrode width and slit width and then, the direction of the chevron pattern at reflect part is setup at 48° [12]. In this case, we can get the same EO characteristics between transmissive and reflective parts even though reduction of reflectance occurs slightly.

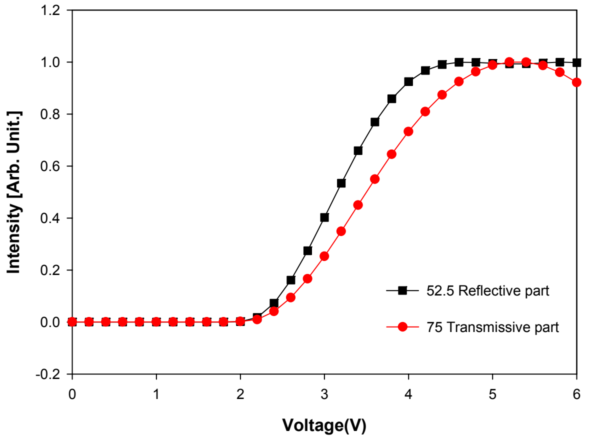


**Fig 3. EO characteristics at reflective part and transmissive part with electrode structure of 50 : 10 which means the ratio between electrode width and slit width.**

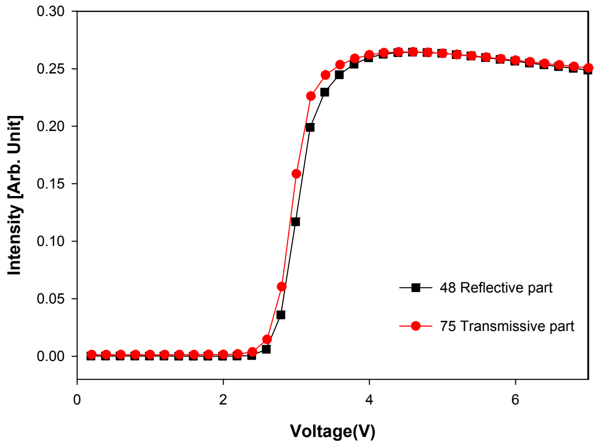


**Fig 4. EO characteristics at decreased patterning angle of reflective electrode with structure of 70 : 5.**

The chevron structure optimized in 48° also does not degrade optical dispersion characteristics as shown in Fig. 5.

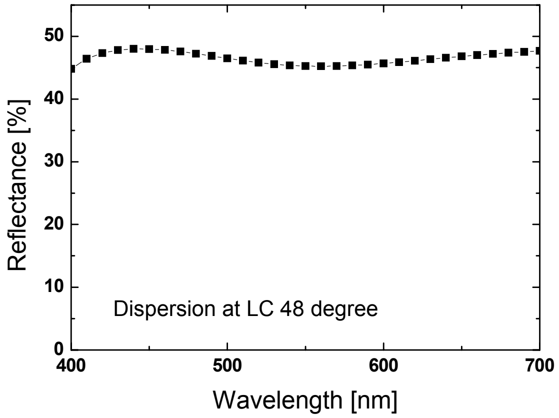


**Fig 5. Dispersion characteristics at bright state of reflective part with the chevron structure of 48°**

## 5. Conclusion

We propose a wide-band PVA transflective LCD with single gamma characteristics by a single cell gap structure. The optical path differences between transmissive and reflective parts are compensated by designing the electrode structure. The wide-band characteristics are realized by adopting two retardation films including inner retardation film which was constructed by Stokes parameters. We expect that the proposed transflective mode will be use at mobile LCD applications.

## 6. Acknowledgements

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