A transflective LCD using PVA mode and optimization of pattern size

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Abstract
In this paper we report the optimization method of the pattern size of the electrodes in PVA LCD for the transflective mode in order to improve the optical characteristics. Moreover, we designed the electrode of PVA LCD so as to remove the driving voltage difference between transmissive mode and reflective mode. As a result, we expect very simple manufacturing process and high optical performance even if complex process such as a multi cell gap process and multi driving method are not applied

1. Introduction
With the increasing demands for portable electronic devices such as mobile phones and personal digital assistants (PDAs), a reflective liquid crystal display is being widely required for personal information display because of light weight and low power consumption. As for indoor environments, however, the reflective display LCD can not be readable under no built-in light. Therefore, recent mobile display devices may have a requirement which can provide readability regardless of built-in light, so that various transflective liquid crystal displays (LCDs) have been proposed.

In general, the basic concept for the design of the transflective LC cell is classified into two types. First is a transflective LCD whose pixel is divided into both of reflective and transmissive subpixels [1-2]. Therefore, a structure of the transflective LC cell should have two different parts in a pixel, which have different cell gap by means of the transmissive and reflective region, so that it requires very complex manufacturing process compared with conventional reflective mode LC cell. Different cell gap could cause different response time and different driving voltage between the transmissive mode and reflective mode. Moreover, it also has the disadvantage that the fringe field effect in the transmissive mode may deteriorate optical performance. Another type for transflective mode has a pixel structure in which the electrode is composed of a transparent electrode and a reflective electrode [3-4]. In this case, the optical design should be carried out with same LC retardation in the both display mode. Therefore, it is very hard to achieve satisfiable optical performance as to both display modes simultaneously.

In this paper, we propose a new transflective LCD using patterned vertically aligned (PVA) mode, which can provide simple manufacturing process and one driving circuit. We calculated the optimized ratio and size of the patterned electrodes in order to achieve maximum optical characteristics and remove the voltage difference between the transmissive mode and reflective mode. By controlling the electrode pattern, we could adjust the total phase retardation between reflective mode in which the light passing through LC layer experience twice time, and transmissive mode in which the light experience one time. So, the region with a small retardation is used in reflective part (r-part) and the region with a large retardation is used in transmissive part (t-part). Moreover, we confirmed that the voltage difference between both of the modes we could be removed. The proposed transflective liquid crystal (LC) cell has the wide viewing angle characteristics since the electric field is distorted by its patterned electrodes.

2. Basic configuration
Figure 1 shows the proposed configuration of the transflective LCD using PVA mode. The insulated reflector is patterned in the lower electrodes. We set the area of the t-part larger than that of the r-part in the ratio of 1:3 and 1: 4 because transmissive mode has higher optical efficiency and more fine viewing characteristics than reflective LCDs. If the voltage is applied to the patterned electrodes, the distribution of the retardation appears periodic. The parts in the transparent electrodes on the lower substrate have

been designed for transmissive mode and the other has been designed for reflective mode.

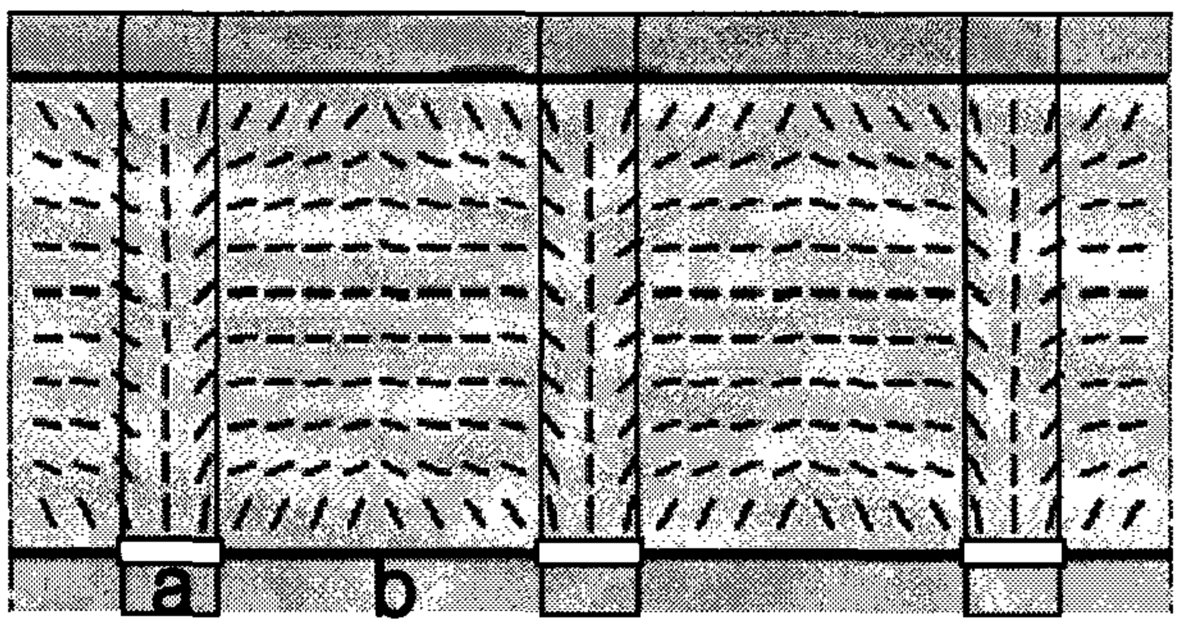


Figure 1. Optical configuration of a transflective LCD using PVA mode. "a" part represents insulated reflector (reflective part) and "b" part represents transparent electrode (transmissive part).

First of all, to decide the width ratio of the r-part and the t-part, we compared the retardation in the ratio of 1:3 with 1: 4. The 2dimMOS was used for the calculation. The cell gap d was 4.2 μm and the applied voltage was 5 V. The specification of the LC material (MLC-6608, Merck) is as following; the dielectric anisotropy is –4.2 ($\varepsilon_e = 3.6$, $\varepsilon_o = 7.8$, negative LC), the refractive anisotropy is 0.083 ($n_e = 1.5578$, $n_o = 1.4748$, reference wavelength is 589 nm), $K_{11} = 16.7$ pN, $K_{22} = 7.3$ pN and $K_{33} = 18.1$ pN. With these informations, we can calculate the effective refractive anisotropy (Δn_{eff}) on the arbitrary path of the incident light by Eq. 1.

$$\Delta n_{eff} = \frac{n_o}{\sqrt{1 - \left(1 - \left(\frac{n_o}{n_e}\right)^2\right)\cos^2\theta}} - n_o \qquad (1)$$

Where, θ is the direction of the incident propagation light. In order to realize the transflective mode, the r-parts require the quarter-wave retardation (137.5 nm) and the t-parts require the half-wave retardation (275 nm). Table 1 shows the calculation. For the reflective part, we assumed the incident angle of the oblique incident beam 20 degree.

As a result, we confirmed that the ratio of the 1:4 is more appropriate than that of the 1:3 for the transflective mode because it can make lager effective retardation at the same condition. Therefore, we have decided the electrode ratio of the transflective mode between reflective part and the transmissive as 1:4. Then we optimized the pattern size of the electrodes to realize the transflective mode with one driving circuit and single cell gap.

Table 1. Comparisons of 1:3 pattern with 1:4 pattern

Transflective ratio (r-part : t-part)	T-part	R-part		
	$d\Delta n_{eff}$	$d\Delta n_{eff}$ (0°)	$d\Delta n_{eff}$ (20°)	Sum
10 μm : 30 μm (1:3)	256.2 nm	103.7 nm	94.8 nm	198.5 nm
8 μm : 32 μm (1:4)	257.5 nm	126 nm	114.4 nm	240.4 nm

3. Results of optical calculation

Table 2 shows the calculated electro-optical characteristics in the case that the transflective ratio between the r-part and the t-part is 8 um to 32 um. In the Table 2, we can obtain the 274.7 nm retardation in the t-part with 6 V. And the total retardation in the r-part is 286.8 nm. These results are enough to obtain the bright state at both t-part and r-part. Instead, however, the driving voltage is too high to drive. Therefore, we needed to reduce the driving voltage, so that we applied another LC material, which have larger refractive anisotropy and dielectric anisotropy than the previous LC material.

Table 2. Retardations of the 8 μm : 32 μm cell according to applied voltage.

		T-part	R-part (0°)	R-part (20°)	Sum
5.5 V	Δn_{eff}	0.0639	0.0329	0.0299	0.0628
	$d\Delta n_{eff}$	268.4 nm	138.2 nm	133.7 nm	266.5 nm
6 V	Δn_{eff}	0.0654	0.0354	0.0309	0.0663
	$d\Delta n_{eff}$	274.7 nm	148.7 nm	138.1 nm	286.8 nm

The absolute value of the pattern size of the electrode have been decided by simulating the electro-optical characteristics with three other pattern sizes – 4 um : 16 um, 6 um : 24 um and 8 um : 32 um, respectively, which sustains 1:4 part ratio. For the calculation, the LC material (MDA-01-2306, Merck) has been used, which has the large dielectric anisotropy ($\Delta\varepsilon$=–5.0, ε_e = 3.9, ε_o = 8.9), the large refractive anisotropy (Δn=0.1204, n_e = 1.6054, n_o = 1.4850 at λ=589 nm), K_{11} = 14.7 pN and K_{33} = 16.8 pN.

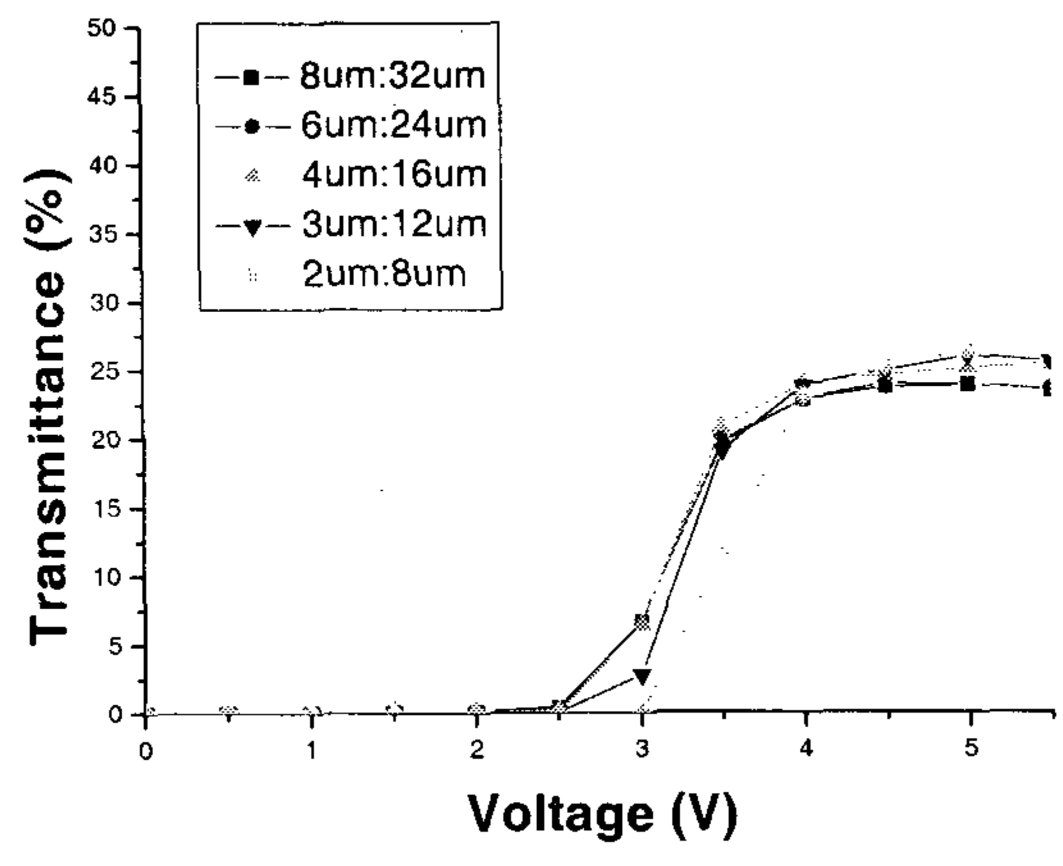
As shown in table 3, the transmittance of the t-part in all cases reached about 45 %. The driving voltage was reduced, but the retardations of the r-parts were not enough to obtain the bright state. So, in order to improve the r-part, we reduced the cell gap to 3.2 μm and increased the applied voltage.

Table 3. Results of calculation for the pattern sizes (d = 4.2 μm)

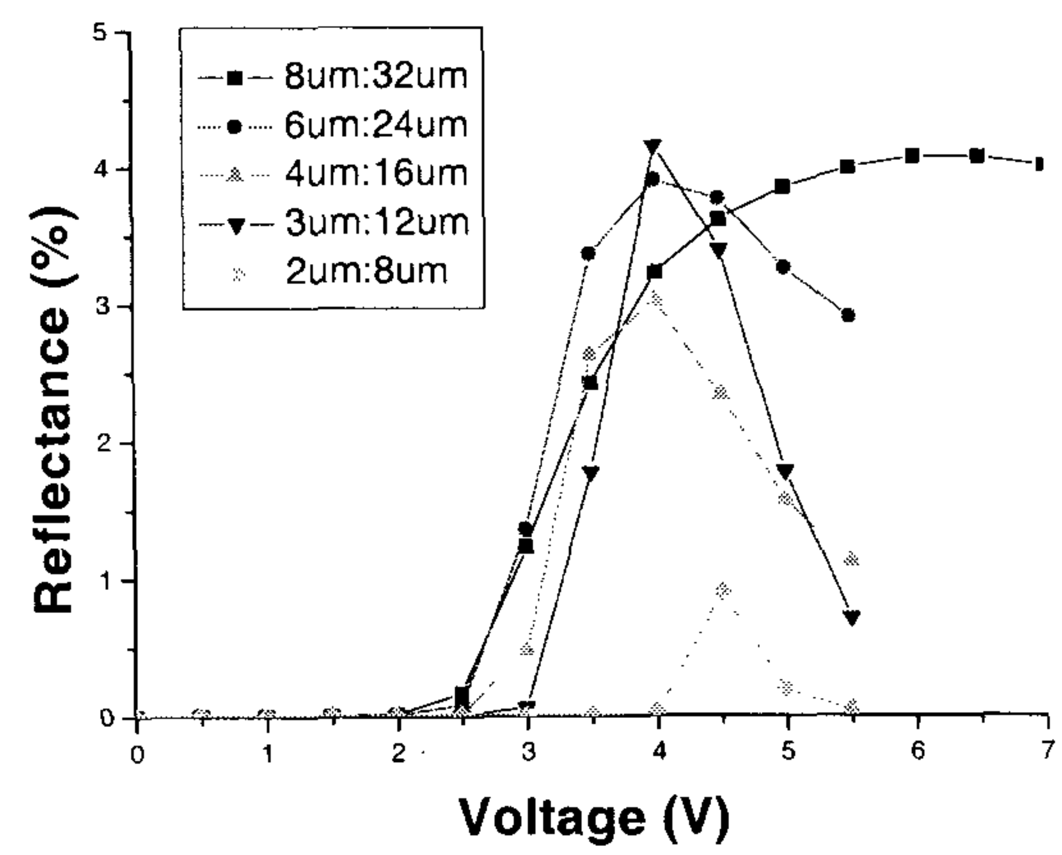
	8 μm : 32 μm	6 μm : 24 μm	4 μm : 16 μm	Applied voltage
Transmittance	45 %			3.2 V
Retardation of r-part	125 nm			
Transmittance	44.3 %			3.3 V
Retardation of r-part	137.4 nm			
Transmittance		44 %		3.1 V
Retardation of r-part		131.6 nm		
Transmittance			41.9 %	3.2 V
Retardation of r-part			128.7 nm	

Table 4 shows calculation results. In the table, three conditions, which are 6 um : 24 um, 4 um : 16 um and 3 um : 12 um, exhibit enough effective retardations at both the transmissive mode and reflective mode simultaneously. The applied voltage was 4.5 V. This results may imply that the transflective LCD using PVA mode can be realized with one driving circuit and single cell gap.

Figure 2 shows the electro-optic characteristics of the transflective LCD. And Fig. 3 shows the viewing angle characteristics of the 6 um : 24 um cell with a compensation film. In the figure, very good viewing angle characteristics are shown.

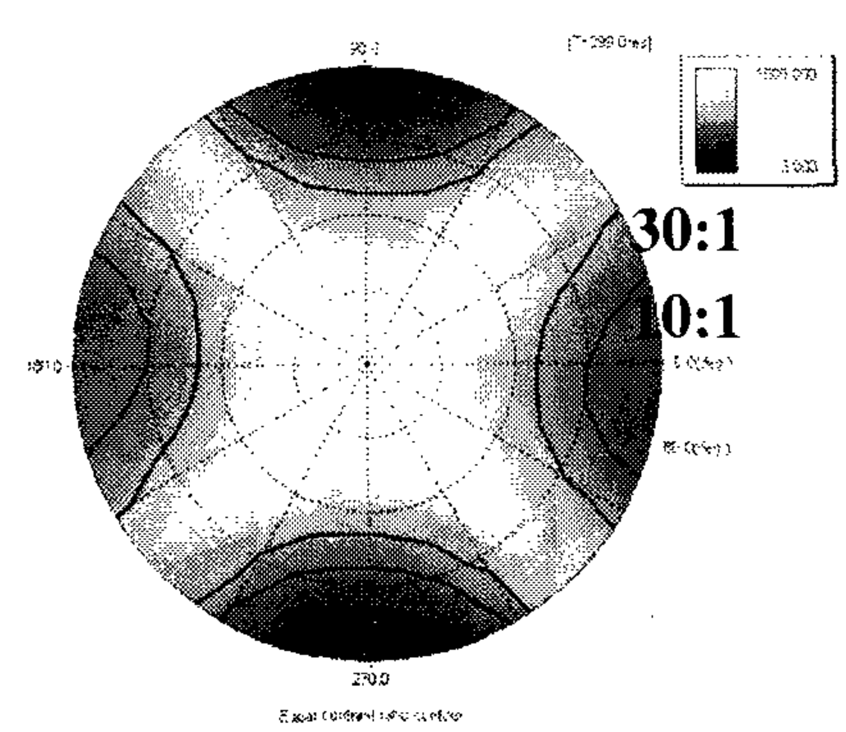


(a)

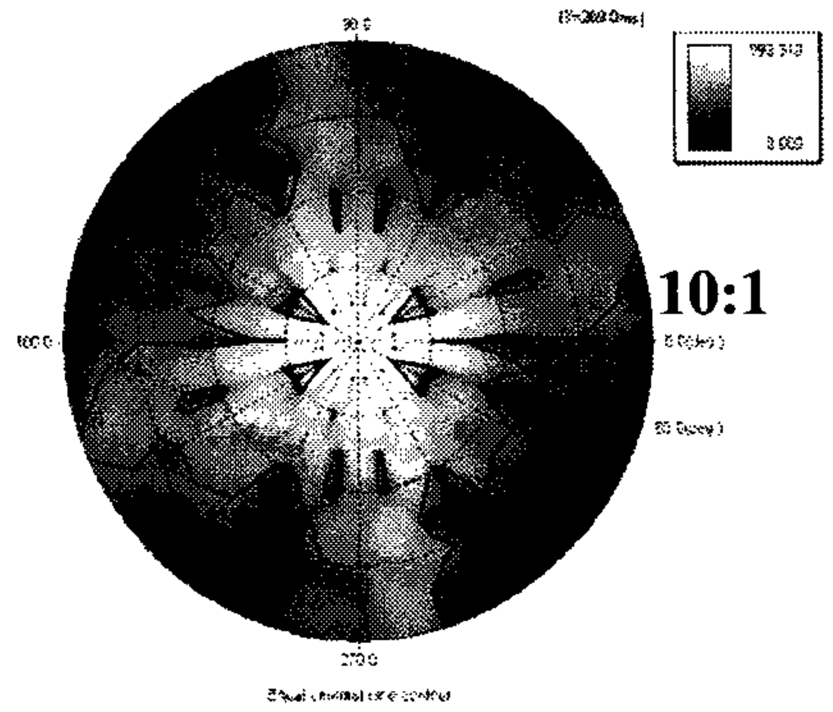


(b)

Figure 2. Electro-optic characteristics of the transflective LCD; (a) the transmittance of a pixel. (b) the reflectance of a pixel.



(a)



(b)

Figure 3. Viewing angle characteristics of the 6 μm : 24 μm transflective cell; (a) the transmissive mode. (b) the reflective mode.

Table 4. Results of calculation for the pattern sizes (d = 3.2 μm)

	8 μm : 32 μm	6 μm : 24 μm	4 μm : 16 μm	3 μm : 12 μm	Applied Voltage
Transmittance	46.1 %				5 V
Retardation of r-part	173.5 nm				
Transmittance		47.3 %			5 V
Retardation of r-part		229 nm			
Transmittance			46.6 %		4.5 V
Retardation of r-part			255.7 nm		
Transmittance			47.5 %		5 V
Retardation of r-part			278.9 nm		
Transmittance				46.6 %	4.5 V
Retardation of r-part				267.5 nm	

4. Conclusion

We optimized the pattern of electrodes in the PVA LCD for transflective mode. We controlled so the optical retardation as to be quarter wave and half wave in the reflective mode part and the transmissive part under single voltage. This implies that we can obtain optimized optical characteristics of the transflective mode with a single driving circuit and a single cell gap. This may provide very simple manufacturing process and cost-down compared with double cell gap process or double driving method. We also confirmed that the optimized transflective LCD has shown very wide viewing angle characteristics.

5. Acknowledgement

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6. References

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