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# Control of liquid crystal director near signal lines and reduction of load of signal lines by optimized pattern of common electrode in the patterned vertical alignment mode

Seong Jin Hwang [a], Sung Min Kim [a], Young Jin Lim [a], Seung Hee Lee [a,*], Gi-Dong Lee [b,*], Jae-Jin Lyu [c], Kyeong Hyeon Kim [c]

[a] *Department of Polymer Nano-Science and Engineering, Chonbuk National University, Chonju, Chonbuk 561-756, Republic of Korea*
[b] *Department of Electronics Engineering, Dong-A University, Pusan 607-735, Republic of Korea*
[c] *LCD R&D Center, LCD Business, Samsung Electronics Corporation, Giheung, Gyeonggi-Do 449-711, Republic of Korea*

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**Abstract**

This study examined the electro-optical characteristics and stability of a liquid crystal director depending on the electrode patterning of a common electrode on the top substrate in patterned vertical alignment (PVA) mode. The new type of common electrode pattern suggests that the dark state of the device is improved by reducing the interfering electrical field caused by the signal lines, which can help to improve the aperture ratio and also the load-on signal lines were reduced, resulting in a decrease in power consumption.


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*Keywords:* Patterned vertical alignment; Liquid crystal; Electrode pattern

## 1. Introduction

The liquid crystal display (LCD) market has many different liquid crystal modes in competition with each other. The conventional well known twisted nematic (TN) mode [1,2] is mainly used in portable displays on account of its high transmittance and low power consumption. However, the TN mode shows a narrow viewing angle, which has led to many wide viewing angle liquid crystal modes being proposed, such as in-plane switching (IPS) [3], fringe-field switching (FFS) [4–6], multi-domain vertical alignment (MVA) [7], and patterned VA (PVA) [8].

Among these, the PVA mode, which has been commercialized in liquid crystal-televisions, shows a very high contrast ratio at the normal direction because the liquid crystal is aligned vertically to the substrate, so that phase retardation of the cell is zero under a crossed polarizer, resulting in a good dark state. Nevertheless, liquid crystal reorientation in the on state is a major problem with PVA mode [9]. In order to generate transmittance in PVA mode, a liquid crystal with negative dielectric anisotropy should tilt downward in four different directions making a 45° angle with respect to the transmission axes of the crossed polarizers because the transmittance is proportional to $\sin^2(2\psi)\sin^2(\delta/2)$, where $\psi$ is the angle between the liquid crystal director and polarizer axis and $\delta$ is the phase difference of the liquid crystal layer. The source for tilting down the liquid crystal is the oblique electric field generated by patterned electrodes on the top and bottom substrate. In thin-film-transistor (TFT)-LCD, there are signal lines, such as data and gate lines. Moreover, when an electrical signal (voltage) is applied to these lines, there is an electric field

* Corresponding authors. Tel.: +82 63 270 2343; fax: +82 63 270 2341.
*E-mail addresses:* lsh1@chonbuk.ac.kr (S.H. Lee), gdlee@dau.ac.kr (G.-D. Lee).

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between the top common electrode and signal lines as well as between the bottom pixel electrodes and signal lines. This interferes with the signals given to the pixel electrodes to present information. In addition, the liquid crystal around the signal lines reorients perpendicular to the field direction, making an angle with respect to the crossed polarizers, which causes light leakage in the dark state. In order to enhance the dark state, this light leakage should be blocked by a black matrix (BM) on the color filter side, which decreases the aperture ratio. On the other hand, such light leakage near the data signal line is automatically blocked in FFS mode, in which the electrode on the top substrate does not exist because the liquid crystal director with positive dielectric anisotropy is aligned parallel to the interfering field direction [10].

Unfortunately, conventional PVA mode has a common electrode over the entire surface including the signal lines and the pixel area. Therefore, there is an intrinsic interference between the common and signal lines or the signal lines and pixel electrodes, resulting in some light leakage near the signal lines. In this paper, the electrode structure was optimized and the electrical interference was minimized between the signal and the other electrodes, which increases the aperture and the contrast ratios of the device.

## 2. Electrode structure and simulation condition

Fig. 1 shows the electrode structure of PVA modes. In the electrode structure of a conventional PVA mode, the common electrode is patterned in an active area but not above the gate and data signal lines. However, in the electrode structure of the improved PVA mode, the common electrode is patterned in an active area but also above the data and gate lines with the exception of the necessary parts (see circles) connecting the adjacent pixels, in order to reduce the interference electric field. In this study, the pixel size of the PVA modes was 88 μm × 264 μm.

An electro-optic characteristics study of the PVA mode was performed based on the simulation using the three-dimensional finite element method (FEM) module of Tech-Wiz LCD (Sanayi System, Korea). The optical transmittance was calculated using the 2 × 2 extended Jones matrix [11]. The liquid crystal has the following physical parameters: Birefringence $\Delta n = 0.79$ at $\lambda = 550$ nm, dielectric anisotropy $\Delta\varepsilon = -4.2$, rotational viscosity $\gamma = 110$ mPa·s, $K11 = 16.7$ pN, $K22 = 7.3$ pN, $K33 = 18.1$ pN. The cell gap is 4 μm.

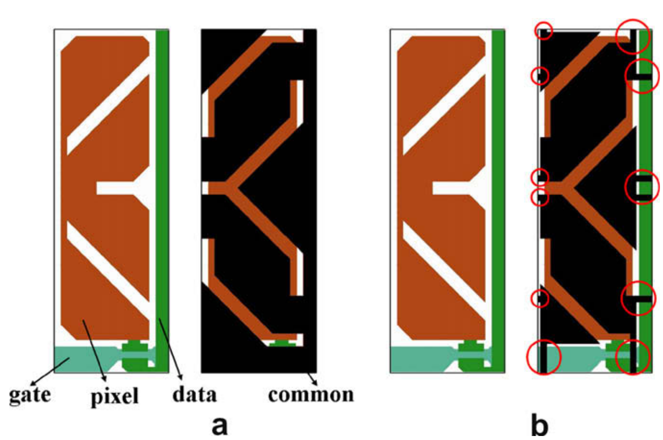


Fig. 1. Electrode structure of the PVA modes: (a) conventional and (b) improved PVA mode.

## 3. Result and discussion

In display devices, the achievement of a perfect dark state is important for realizing a high contrast ratio. In LCDs, the region of light leakage by the interfering signals of both the gate and the data lines when a pixel is in the

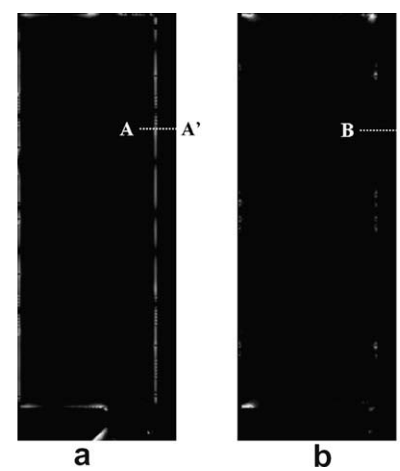


Fig. 2. Light leakage in the dark state: (a) conventional and (b) improved PVA mode.

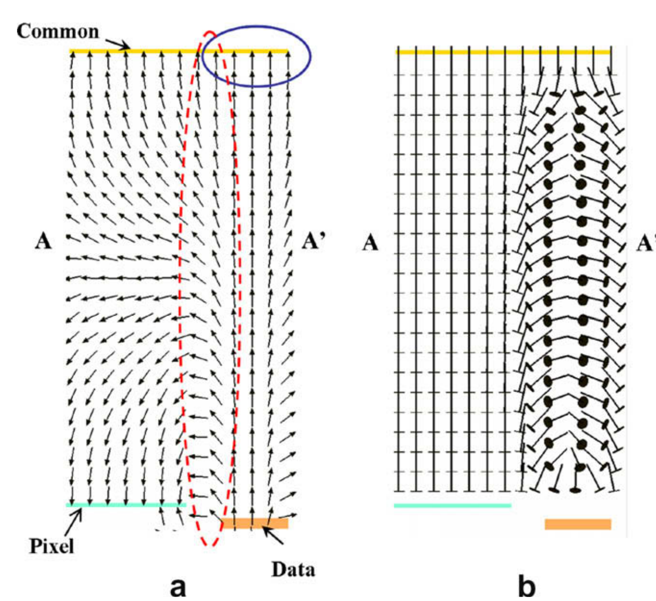


Fig. 3. (a) Electric field and (b) liquid crystal director distribution of the conventional PVA mode in the dark state.

dark state are defined initially, and the region of BM is defined accordingly. Therefore, the dark state of PVA mode near the signal lines was examined according to the structures. In order to examine the light leakage of a given pixel in the dark state by the signal lines, the applied voltages for a pixel electrode, common electrode, data line, and gate line were 6 V, 6 V, 12 V, and −10 V, respectively. In this way, there was no potential difference between the pixel and common electrode, realizing a dark state in an active area. However, a liquid crystal around the signal lines will be disturbed by the potential difference of 6 V between the data and pixel and common, and −16 V between the gate and pixel and common electrodes. The potential difference between the signal lines and pixel electrode is the largest case in real dot inversion-driving for an active matrix LCD.

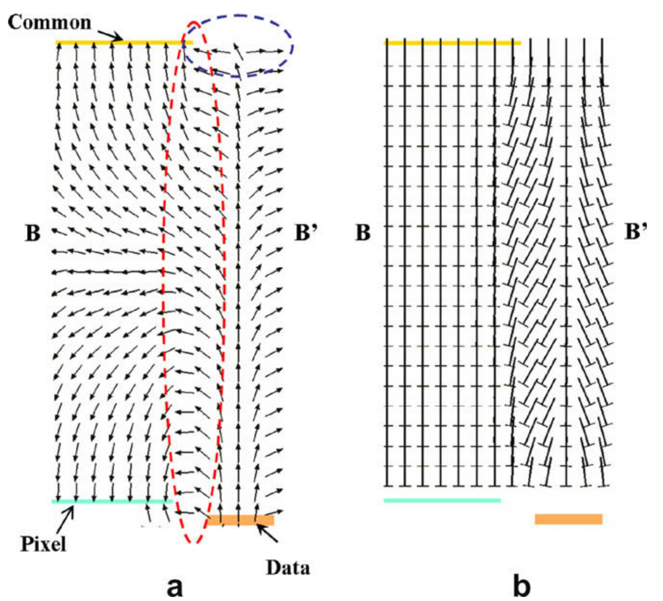


Fig. 4. (a) Electric field and (b) liquid crystal director distribution of the improved PVA mode in the dark state.

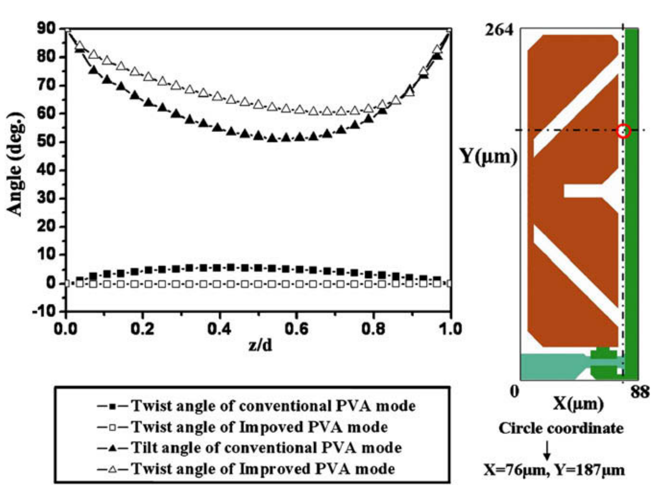


Fig. 5. Liquid crystal orientation in the tilt and twist angle of the conventional and improved PVA modes.

Fig. 2 shows the light leakage in the dark state in each case. The light leakage in the dark state along the data and gate lines is much lower in the improved PVA mode than in the conventional PVA mode. The result shown in Fig. 2 can be understood from the field distribution and corresponding liquid crystal director profile.

Fig. 3 shows the electric field and director distribution of conventional PVA mode in the dark state. The common electrode in conventional PVA mode is covered over the entire surface including the signal lines and the pixel area. As shown in Fig. 3a, a strong vertical electrical field is generated between the signal line and common electrode when a potential difference is generated between them, and an oblique electric field is formed between the signal line and pixel electrode. Due to this field distribution, the liquid crystal should tilt downward in a semicircular shape above the signal line but in a random azimuthal direction because the vertically aligned liquid crystal can tilt down in any direction due to the vertical electric field, as shown in Fig. 3b. Accordingly, light leakage in the dark state occurs largely near the signal lines.

Fig. 4 shows the electric field and director distribution of the improved PVA mode in the dark state. The common electrode in the improved PVA mode is patterned above the signal lines, i.e. there is no common electrode above

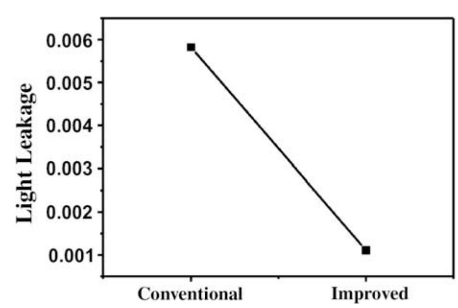


Fig. 6. Light leakage of the conventional and improved PVA modes at the normal direction in a dark state.

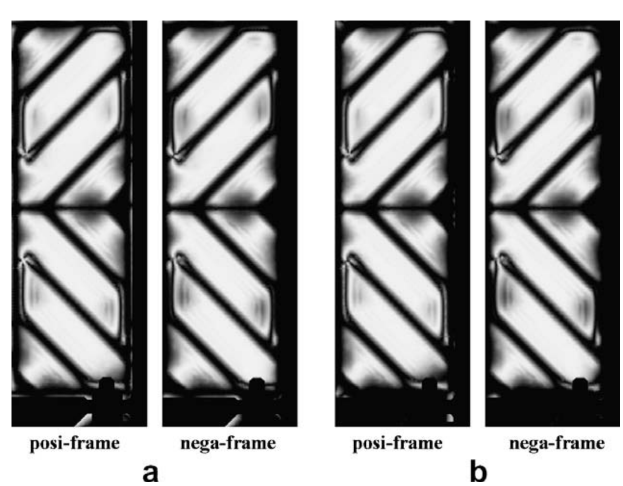


Fig. 7. Transmittance distribution at the operation voltage: (a) conventional and (b) improved PVA mode.

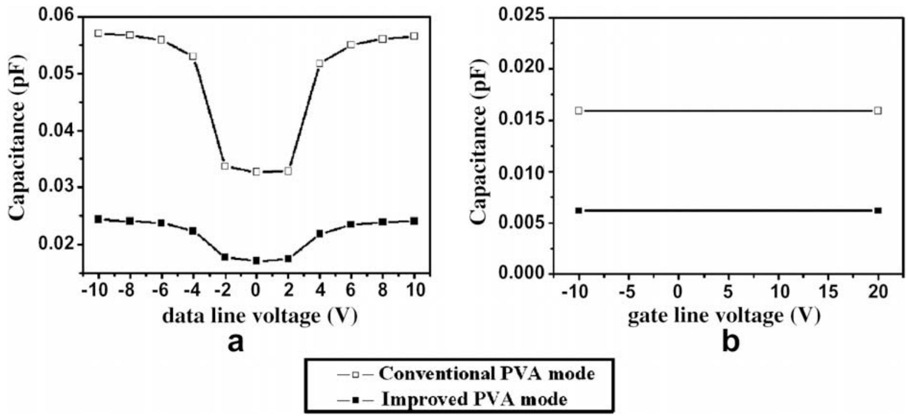


Fig. 8. Capacitance of the conventional and improved PVA modes: (a) capacitance of the common-data line (b) capacitance of the common-gate lines.

the signal lines. In this way, the electric field intensity becomes weak in the vertical direction and there is only an oblique field between the data and pixel electrodes, as shown in Fig. 4a. Consequently, the liquid crystals above the center of the data line remain vertically aligned, and they tilt downward in both the left and right directions symmetrically with respect to the center of the data line, as shown in Fig. 4b. In addition, the liquid crystals tilt down only slightly because of the decrease in the vertical electric field intensity resulting in minimal light leakage between the signal line and pixel electrode in the dark state.

Fig. 5 shows the liquid crystal orientation in the tilt and twist angle in the conventional and improved PVA modes in the mid-point (see circle) between the signal line and pixel electrode. As shown in Figs. 3 and 4, the generation of a tilt angle in the improved PVA mode is smaller than in the conventional PVA mode, which gives rise to a much lower $\delta$ in the improved PVA mode than that in the conventional one. In addition, the twist angle of liquid crystals in the improved PVA mode is almost zero, which is in the same direction as transmission axes of the crossed polarizer. Consequently, $\psi$ is close to zero and $\delta$ is very small in the improved PVA, which minimizes light leakage in the improved PVA mode at the normal direction. Fig. 6 shows that the calculated amount of light leakage is reduced by 80.9% in the improved PVA mode compared with the conventional PVA mode.

The improved PVA mode has an excellent dark state. However, superior impact in a dark state would not be a strong merit if the transmittance of improved PVA mode in the white state is smaller than that of the conventional PVA mode. This was examined by calculating the transmittance distribution at an operation voltage in both the positive- and negative-frame. Both structures showed the same transmittance, as shown in Fig. 7.

In addition to the electro-optic characteristics of a liquid crystal device, a decrease in the load of the electrical signals is important because it can reduce the power consumption of the device. In general, the load of a signal line is defined by the delay time $\tau_c$ as follows:

$$\tau_c = RC \tag{1}$$

where $R$ is the resistance of the signal line, and $C$ is the capacitance given to a signal line. In particular, when the size of the TFT-LCDs becomes very large (over 100”) [12], the decrease in the delay time is essential for generating images over the entire display perfectly. Assuming $R$ is the same in both the conventional and improved PVA modes, a decrease in $C$ will reduce not only the delay time but also the power consumption because it is linearly proportional to $C$.

Fig. 8 shows the capacitance between the common electrode and data or gate line. The $C$ in the improved PVA cell is smaller than those in the conventional PVA cell. Therefore, the removal of the top common electrode will decrease the overlapped area between the common electrode and signal lines, resulting in a decrease in $C$. In addition, the decrease in the load opens the possibility of reducing the width of the signal lines because a slight increase in $R$ by narrowing the electrode width in the improved PVA will give rise to the same load in the conventional PVA cell, which has an advantage in increasing the aperture ratio.

## 4. Conclusion

This paper proposed an improved PVA mode where the common electrode is optimized to the pattern above the signal lines. This approach contributes to the stabilization of a liquid crystal director along the signal lines and reduces the electrical load of the signal lines, which improves the aperture ratio and reduces the level of power consumption in the PVA mode without additional cost.

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