P-138: A 12-domain MVA-LCD with Wide Viewing Angle and High Transmittance

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Abstract
A 12-domain MVA-LCD is proposed and investigated through a 3-D simulator. The MVA-LCD has the advantages of wide viewing angle, high transmittance, fast response time and small color shift with our proposed wide view circular polarizers that consist of a series of uniaxial compensation films.

1. Introduction
With the quick development and expansion of liquid crystal display (LCD) market, high transmittance, fast response, high contrast ratio and wide viewing angle are usually required for high end LCD devices, such as large screen monitors and TVs [1]. The normally black vertical alignment (VA) LCD exhibits an excellent contrast ratio. To get wide viewing angle, film-compensated multi-domain vertical alignment (MVA) structure is needed. The state-of-the-art MVA LCDs use four and eight domains [2, 3]. More domains give a more symmetric viewing angle, but the light efficiency is sacrificed.

In this paper, we propose a 12-domain MVA using two sets of double Y-shaped slits on the respective pixel and common electrodes. We simulate the LCD performances using a 3-D simulator which combines the finite element method (FEM) and finite difference method (FDM). The electro-optic properties of the MVA LCD under various slit widths and different types of polarizers are characterized by the time-dependent transmittance curve, the color shift diagram and the viewing angle contour bar. We demonstrate a MVA-LCD with wide viewing angle, high transmittance, fast response time and small color shift using the proposed wide view circular polarizers that consist of a series of uniaxial compensation films.

2. Results and Discussion
2.1 Device Design and Simulation Parameters
Figure 1 shows the proposed MVA electrode structure where the double Y-shaped slits are arranged alternatively on the pixel and common electrodes. The slit legs are preferred to be equally separated at 120° in a single Y slit. During simulation, we chose the MVA device with an average slit leg length of 25 µm while the slit width is varied from 3, 5 to 7 µm. The cell gap is 4 µm and a negative LC material Merck MLC-6608 is used for simulations. The linear polarizer pair has a maximum light transmittance of 35%.

Fig.1: The proposed MVA electrode structure.
device are evaluated using the extended Jones matrix method [5]. The LC layer is modeled as a stack of uniaxial homogeneous layers. Here, we assume the reflections between interfaces are negligible. Therefore, the transmitted electric field is related to the incident electric field by

$$
\begin{bmatrix}
E_x \\
E_y
\end{bmatrix}_{N+1} = \mathbf{J} \begin{bmatrix}
E_x \\
E_y
\end{bmatrix}_1 = \mathbf{J}_{Ext} \mathbf{J}_N \mathbf{J}_{N-1} \cdots \mathbf{J}_2 \mathbf{J}_{Ent} \begin{bmatrix}
E_x \\
E_y
\end{bmatrix}_1,
$$

where $\mathbf{J}_{Ext}$ and $\mathbf{J}_{Ent}$ are the correction matrix considering the transmission losses in the air-LCD interface, which are given by

$$
\mathbf{J}_{Ext} = \begin{bmatrix}
2 \cos \theta_p & 0 \\
\cos \theta_p + n_p \cos \theta_k & 2 \cos \theta_k \over \cos \theta_k + n_p \cos \theta_p
\end{bmatrix},
\mathbf{J}_{Ent} = \begin{bmatrix}
2 n_p \cos \theta_k & 0 \\
\cos \theta_p + n_p \cos \theta_k & 2 n_p \cos \theta_p \over \cos \theta_k + n_p \cos \theta_p
\end{bmatrix}.
$$

Correspondingly, the overall optical transmittance is represented as

$$
t_{op} = \frac{|E_{x,N+1}|^2 + \cos^2(\theta_p) |E_{y,N+1}|^2}{|E_{x,1}|^2 + \cos^2(\theta_p) |E_{y,1}|^2},
$$

where $n_p$ is the index of refraction of the polarizer, and $\theta_p$ is given by

$$
\theta_p = \sin^{-1}(\sin(\theta_k) / \Re((n_{e,p} + n_{o,p})/2)),
$$
in which $n_{e,p}$ and $n_{o,p}$ are the two refractive indices of the polarizer, and $\theta_k$ is the azimuthal angle of the incident wavevector, $k$.

Figure 2 is a typical simulated LC director distribution of the VA cell at $V=5 \text{ V}_{\text{rms}}$ and the slit width is $3 \mu m$. From the top view, the LC directors are divided into twelve evident domains. It indicates that a multi-domain LCD device can be formed from the double Y-shaped slits under the application of electric field.

2.3 Time-dependent Transmittance under Crossed Linear Polarizers

Figure 3 plots the time-dependent transmittance (T-t) of the LCD structure with three slit widths at $V=5 \text{ V}_{\text{rms}}$ under crossed linear polarizers. As the slit width increases, the LC directors respond to the electric field quickly in the initial stage but slow to get saturation. And the transmittance is lowered due to the reduction of the effective aperture ratio. The saturated transmittance for the $3 \mu m$ slit width is $22.7\%$ while that of $7 \mu m$ drops to $19\%$. Therefore, it is important to choose the appropriate slit width while designing the MVA configuration so that the light efficiency will not be sacrificed too much.

2.4 Time-dependent Transmittance under Crossed Circular Polarizers

The T-t curves with the varied slit widths under crossed circular polarizers are shown in Fig. 4, where the applied voltage is $5 \text{ V}_{\text{rms}}$. Compared to the results shown in Fig. 3, the transmittance of a MVA under circular polarizers is $\sim30\%$ higher than that of using linear polarizers. The maximum light transmittance of the MVA with $3 \mu m$ slit width reaches $32.2\%$ under circular polarizers, which is a $33\%$ improvement than that of using linear polarizers. Moreover, the response time, especially in the rise period, is reduced noticeably. For example, the rise time of a MVA with $3 \mu m$ slit width under linear polarizers is $21.5 \text{ ms}$ (from $10\%$ to $90\%$ transmittance), but is reduced to $14 \text{ ms}$ when the circular
polarizers are used. This improvement is particularly important for TV and computer monitor applications where fast response time is needed.

![Fig.3: The T-t curves under crossed linear polarizers.](image)

**Fig.3:** The T-t curves under crossed linear polarizers.

![Fig.4: The T-t curves under crossed circular polarizers.](image)

**Fig.4:** The T-t curves under crossed circular polarizers.

### 2.5 Color Shift

Figure 5 compares the color shift of the 12-domain MVA-LCD with that of a 6-domain MVA-LCD using single double Y-shaped slits on the pixel electrode. The white light is incident from 50° and scanned across the whole azimuthal range under the CIE 1931 chromaticity diagram. There is still a slight color shift phenomenon in the 12-domain MVA-LCD, especially in the short and long wavelength regions. It is much less than that of 6-domain MVA-LCD since the formed 12 domains can effectively self-compensate each other topologically. An optimized device design will eliminate the color shift further.

![Fig.5: Comparison of color shift between (a) 12-domain and (b) 6-domain MVA-LCDs.](image)

**Fig.5:** Comparison of color shift between (a) 12-domain and (b) 6-domain MVA-LCDs.

### 2.6 Viewing Angle under Crossed Linear Polarizers

Figure 6 plots the iso-contrast contour of a 12-domain MVA-LCD under crossed linear polarizers, where the slit width is 3 µm, the applied voltage is 5 Vrms and the wavelength $\lambda=550$ nm. Two sets of uniaxial films, a positive A-plate and a negative C-plate, are placed after the polarizer and before the analyzer. The film’s $\Delta n d$ value is 93.2 nm and -85.7 nm, respectively. The optimized compensation film design is to lower the oblique light leakage of the crossed linear polarizers [6]. Typically, the light leakage of the film-compensated MVA can be reduced to the level of $10^{-5}$ at different oblique angles. Correspondingly, the 12-domain MVA-LCD demonstrates a high contrast ratio of better than 5000:1 at ±40°, and at the iso-contrast view cone of ±80° it still maintains a contrast ratio higher than 1300:1.
2.7 Viewing Angle using two Wide-View Circular Polarizers

Figure 7 plots the iso-contrast contour of a 12-domain MVA-LCD under two crossed wide-view circular polarizers, where the slit width is 3 µm and V=5 Vrms. The wide-view circular polarizers consist of a series of uniaxial compensation films (3 A-plate and 2 C-plates), where the A-C-A film arrangement acts as a quarter-wave plate, and the additional A-plate and C-plate further reduce the viewing angle sensitivity of the film-laminated circular polarizer [7]. The films are placed in the mirror image style after the polarizer and before the analyzer, respectively. At a single wavelength $\lambda=550$ nm, the contrast ratio remains higher than 1000:1 at $\pm50^\circ$ viewing cone. In the whole viewing range, the contrast ratio is as high as 200:1. When a broadband color filter is used, the contrast ratio will be lowered slightly.

3. Conclusions

A new MVA mode with twelve domains is proposed and its performances analyzed using a 3-D simulator. The device shows a small color shift under the CIE 1931 chromaticity diagram. The 12-domain MVA-LCD demonstrates a high contrast ratio of 1300:1 in the entire viewing cone under crossed linear polarizers when the compensation films are optimized. If the circular polarizers are used, the light transmittance is evidently improved and the response time is shortened. Wide viewing angle circular polarizers consisting of a series of uniaxial films are optimized to obtain high contrast ratio and to enhance viewing angle. In the entire viewing cone, the 12-domain MVA LCD exhibits a 200:1 contrast ratio. These advantages make the proposed 12-domain MVA LCD attractive for high quality TV and computer monitor applications.

4. Acknowledgements

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5. References