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A two dimensional liquid crystal simulation for thin film transistor liquid crystal displays

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A two-dimensional liquid crystal simulation, whose electrode configuration corresponds to that in a thin film transistor liquid crystal display (TFT-LCD), was carried out. Simulation results show that the lateral field between buslines and pixel electrode forms a reverse tilt domain. This reverse tilt domain leads to the disclination on the pixel electrode. The distance from the pixel electrode edge to this disclination location depends on the dielectric anisotropy and elastic constant for the liquid crystal. A small dielectric anisotropy or large elastic constant makes this distance small.

1. Introduction

The thin film transistor liquid crystal display (TFT-LCD) pixel size becomes smaller for high resolution displays. Several TFT-LCDs, with less than 100 μm-sized pixels, have been reported [1, 2]. In such pixels, the field between buslines and pixel electrode causes a disclination border between the reverse tilt domain and the normal tilt domain and thus reduces the contrast ratio.

The numerical method to simulate this reverse tilt disclination has been developed and its dependence on pretilt angle has been reported [3, 4].

This paper describes how the reverse tilt disclination on TFT-LCDs is formed and shows its dependence on the elastic constant and dielectric anisotropy for the liquid crystal.

2. Numerical method

The authors' calculation procedure is the same as that used in [2]. The equation used for calculating the nematic liquid crystal director orientation includes one elastic constant term, as in [2], in addition to the chirality term.

The authors' simulated liquid crystal layer has a TN (twisted nematic) structure. One pixel of a TFT-LCD is shown in figure 1. The TN liquid crystal is driven by the voltage applied to a pixel electrode and a common electrode. The pixel electrode voltage is applied by a busline through a TFT. We calculated numerically in the two dimensional plane as shown in figure 1. Figure 2 shows the actual configuration. This pixel has two buslines, one pixel electrode and one common electrode, where the pixel corresponds to that for a typical TFT-LCD.

Three voltage waveforms applied to buslines, pixel electrode and common electrode, are shown in figure 3. $V_{PIXEL} = 1{\cdot}5$ V (less than the TN threshold voltage V_{TH}) is first applied and after 34 ms, $V_{PIXEL} = 3{\cdot}5$ V (more than V_{TH}) is applied to the pixel electrode. Assuming normally white mode, the simulated pixel will switch from white to black.

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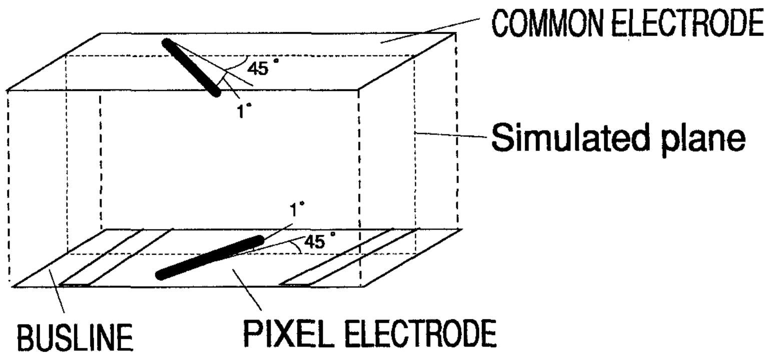

Figure 1. Simulated alignment configuration of the twisted nematic structure.

3. Busline effect

Figures 4–6 indicate time-sequence results, in which the dielectric anisotropy ($\Delta\varepsilon$) and elastic constant (K) for the liquid crystal are respectively 8 and $1{\cdot}5 \times 10^{-11}$ N. Time T in these figures corresponds to that in figure 3. The bold director lines in each figure are reversely-tilted against the pretilt direction. As these figures show, the field between the busline and the pixel electrode initially forms a reverse tilt domain, which grows with time.

Figures 7–9 show time-sequence results, in which $V_{\mathrm{PIXEL}} = 3{\cdot}5$ V. The solid line in each figure shows transmittance for normally-incident light in the normally-white mode. In figure 7, just after $V_{\mathrm{PIXEL}} = 3{\cdot}5$ V is applied to the pixel electrode, the left-hand side directors on the pixel electrode are already reversely tilted, and the right-hand side ones are normally tilted, according to the pretilt direction. Both tilted domains reduce the transmittance. With time, this transmittance decreases from the right-hand side of the pixel electrode (see figure 8). The directors on the pixel electrode

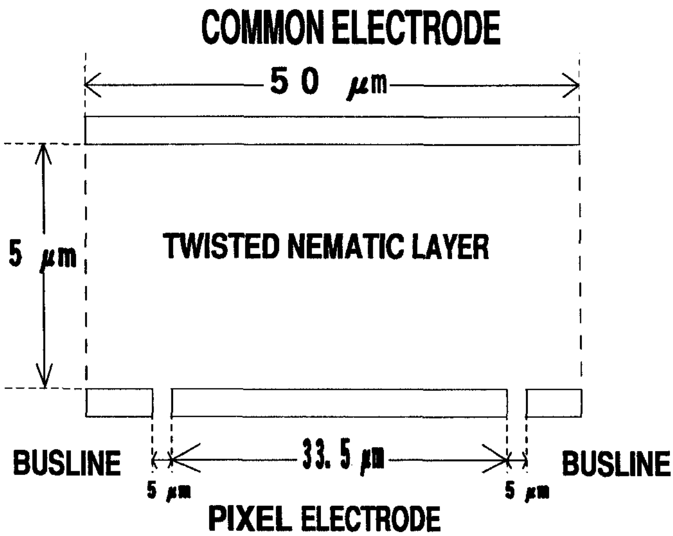

Figure 2. Electrode configuration on two-dimensional liquid crystal simulation.

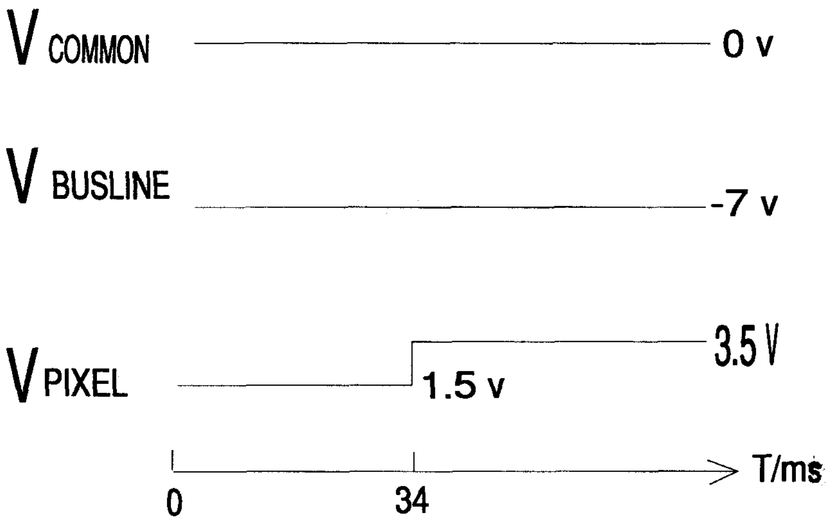

Figure 3. Voltage waveforms applied to each electrode.

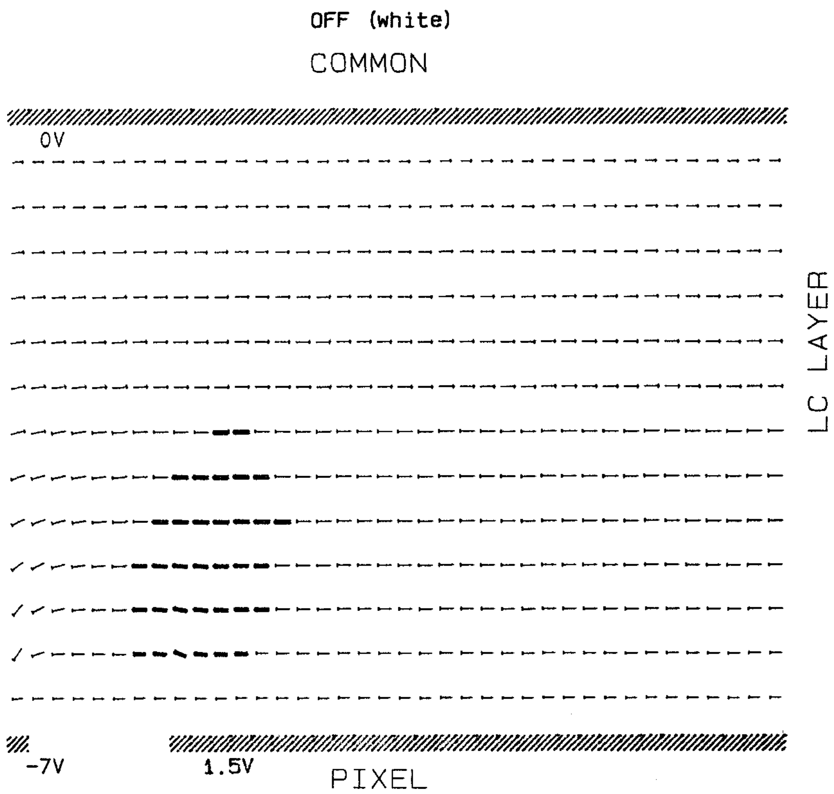

Figure 4. Simulation result at $T = 0{\cdot}5\,\mathrm{ms}$, $K = 1{\cdot}5 \times 10^{-11}\,\mathrm{N}$, $\Delta\varepsilon = 8$.

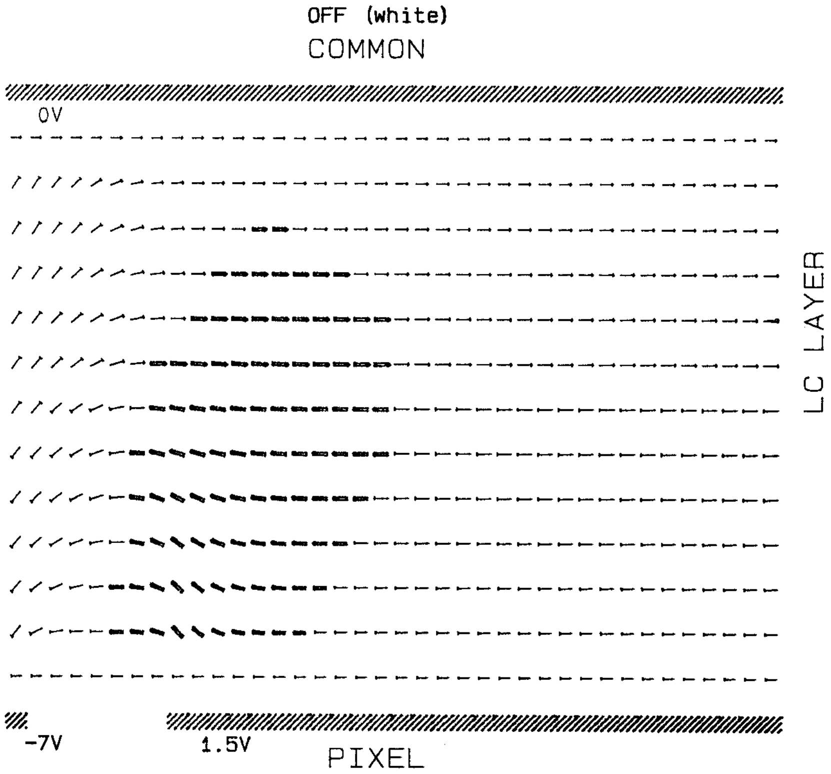

Figure 5. Simulation result at $T = 7{\cdot}0$ ms, $K = 1{\cdot}5 \times 10^{-11}$ N, $\Delta\varepsilon = 8$.

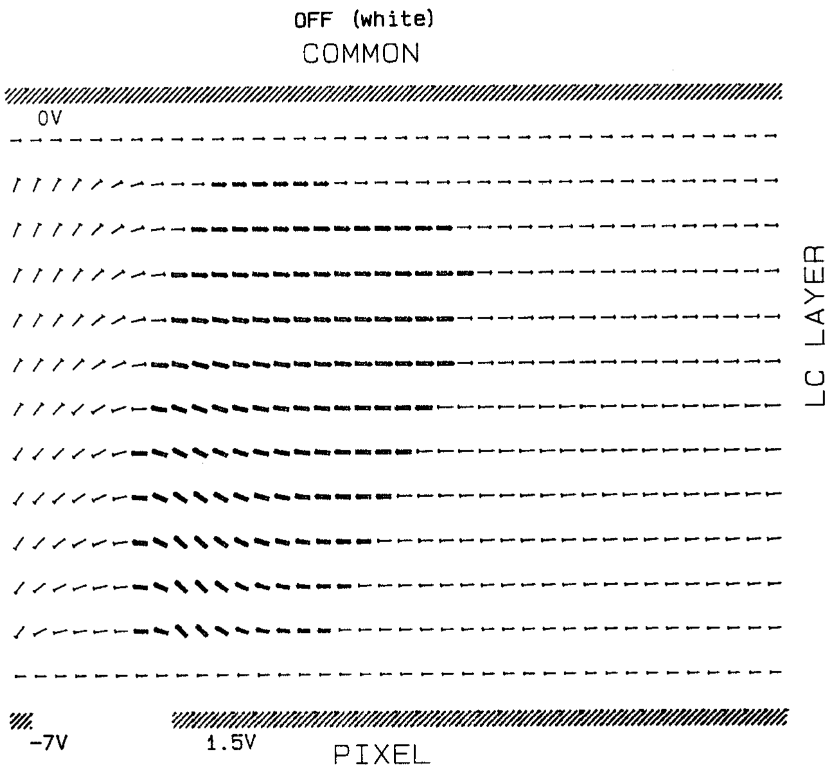

Figure 6. Simulation result at $T = 15{\cdot}0$ ms, $K = 1{\cdot}5 \times 10^{-11}$ N, $\Delta\varepsilon = 8$.

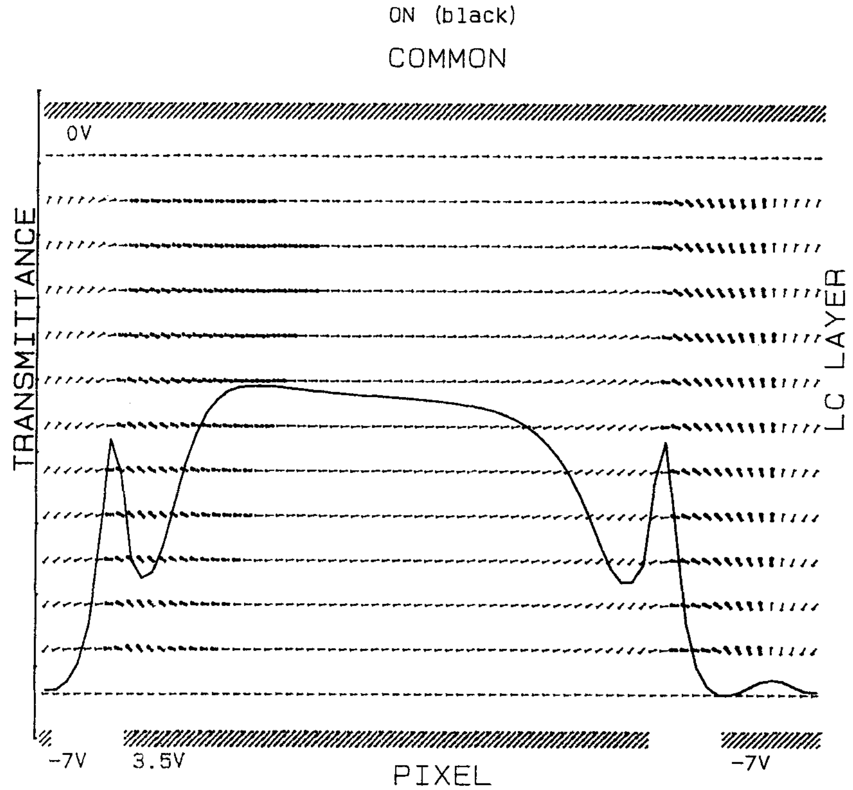

Figure 7. Simulation result at $T = 34$ ms. The solid line in the figure shows calculated transmittance $K = 1{\cdot}5 \times 10^{-11}$ N, $\Delta\varepsilon = 8$.

center are normally tilted, as shown in figure 9 and the transition region between the normal tilt domain and the reverse tilt domain has light leakage on the pixel electrode.

4. Dielectric anisotropy dependence

To determine the dielectric anisotropy dependence, simulation with a small dielectric anisotropy was carried out ($\Delta\varepsilon = 4$, $K = 1{\cdot}5 \times 10^{-11}$ N). This simulation result is shown in figures 10 and 11.

Figures 9 and 10 respectively show the results at $T = 50$ ms with $\Delta\varepsilon = 8$ and $\Delta\varepsilon = 4$. Compared with figure 9, the reverse tilt domain in figure 10 has a smaller size.

Figues 4 and 11 respectively show the results at $T = 0{\cdot}5$ ms with $\Delta\varepsilon = 8$ and $\Delta\varepsilon = 4$. The initially induced reverse tilt domain in figure 11 is smaller than that in figure 4.

This fact is due to the following. Because of small dielectric anisotropy, the liquid crystal director orientation is insensitive to the field between the buslines and the pixel electrode. The reverse tilt domain on the left-hand side of a pixel electrode, cannot grow more after V_{PIXEL} is more than V_{TH}, as shown in figure 10.

5. Elastic constant dependence

To determine the elastic constant dependence, a simulation was carried out with a small elastic constant ($\Delta\varepsilon = 8$, $K = 5 \times 10^{-12}$ N). The simulation results are shown

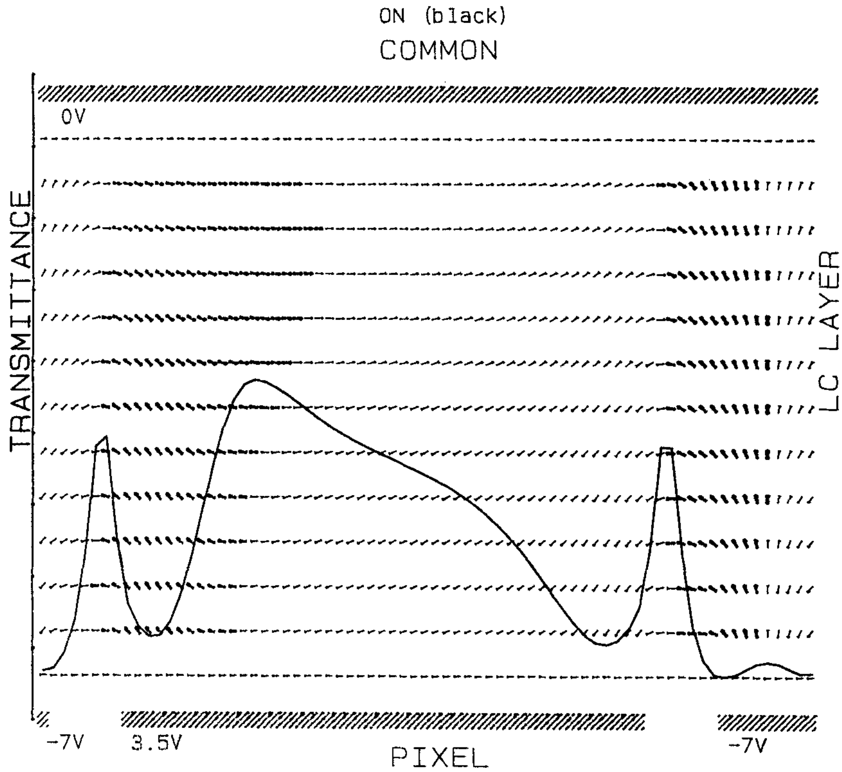

Figure 8. Simulation result at $T = 40\,\mathrm{ms}$. The solid line in the figure shows calculated transmittance $K = 1{\cdot}5 \times 10^{-11}\,\mathrm{N}$, $\Delta\varepsilon = 8$.

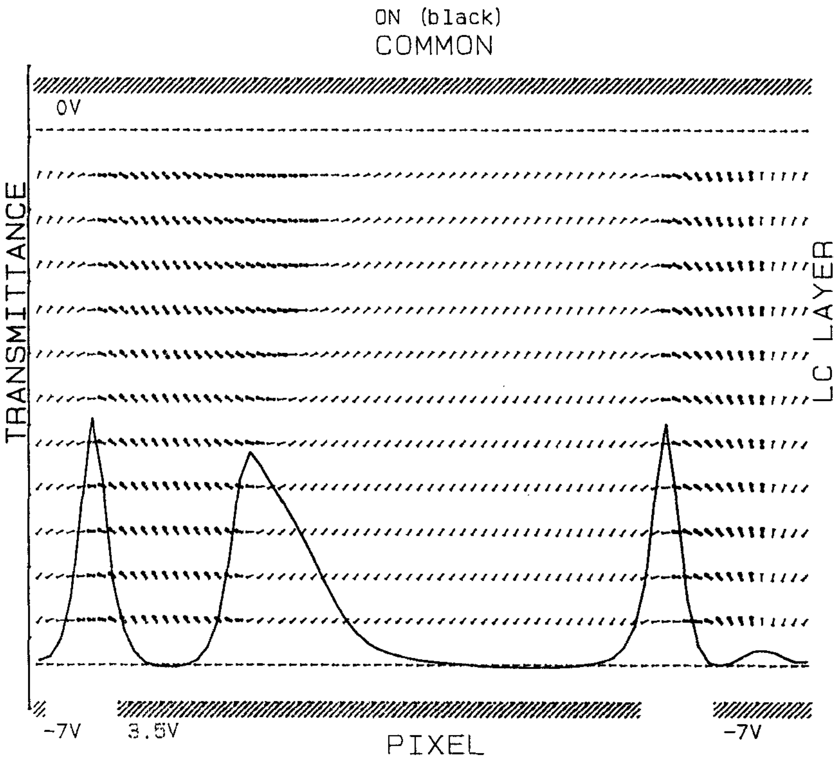

Figure 9. Simulation result at $T = 50\,\mathrm{ms}$. The solid line in the figure shows calculated transmittance $K = 1{\cdot}5 \times 10^{-11}\,\mathrm{N}$, $\Delta\varepsilon = 8$.

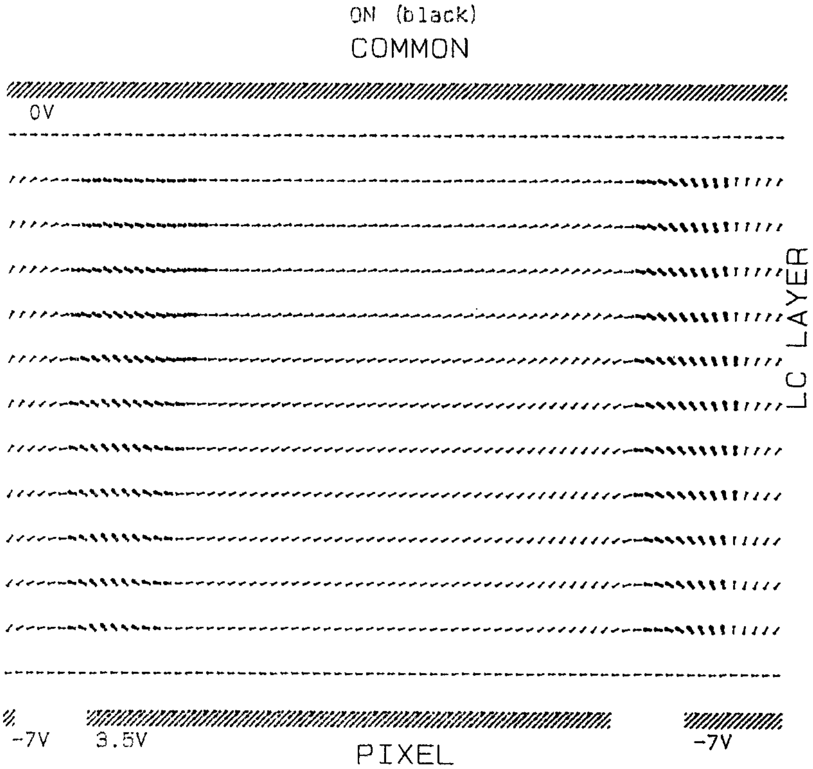

Figure 10. Simulation result at $T = 50\,\mathrm{ms}$, $K = 1{\cdot}5 \times 10^{-11}\,\mathrm{N}$, $\Delta\varepsilon = 4$.

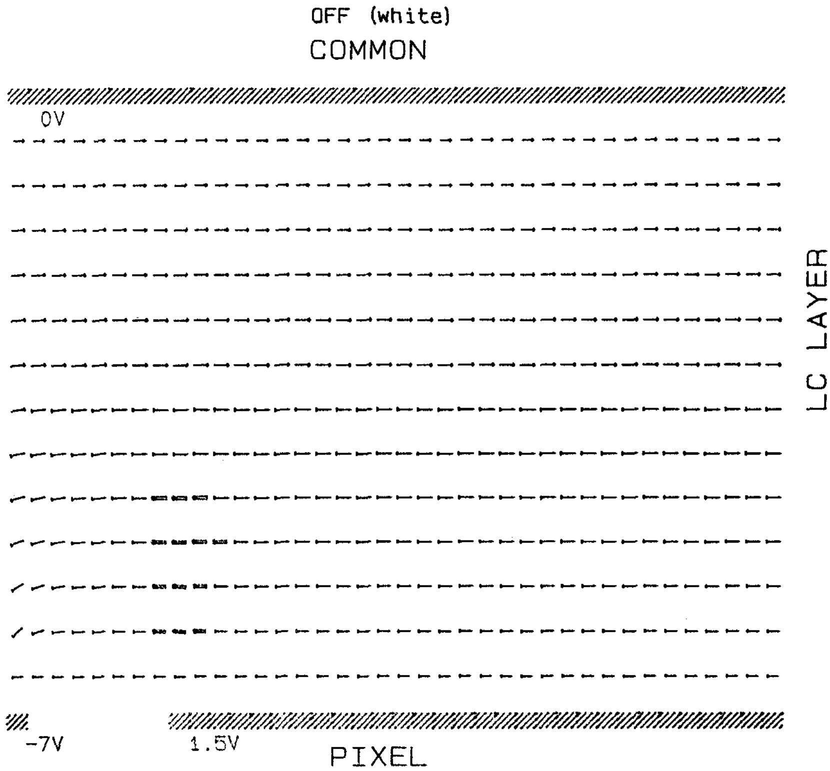

Figure 11. Simulation result at $T = 0{\cdot}5\,\mathrm{ms}$, $K = 1{\cdot}5 \times 10^{-11}\,\mathrm{N}$, $\Delta\varepsilon = 4$.

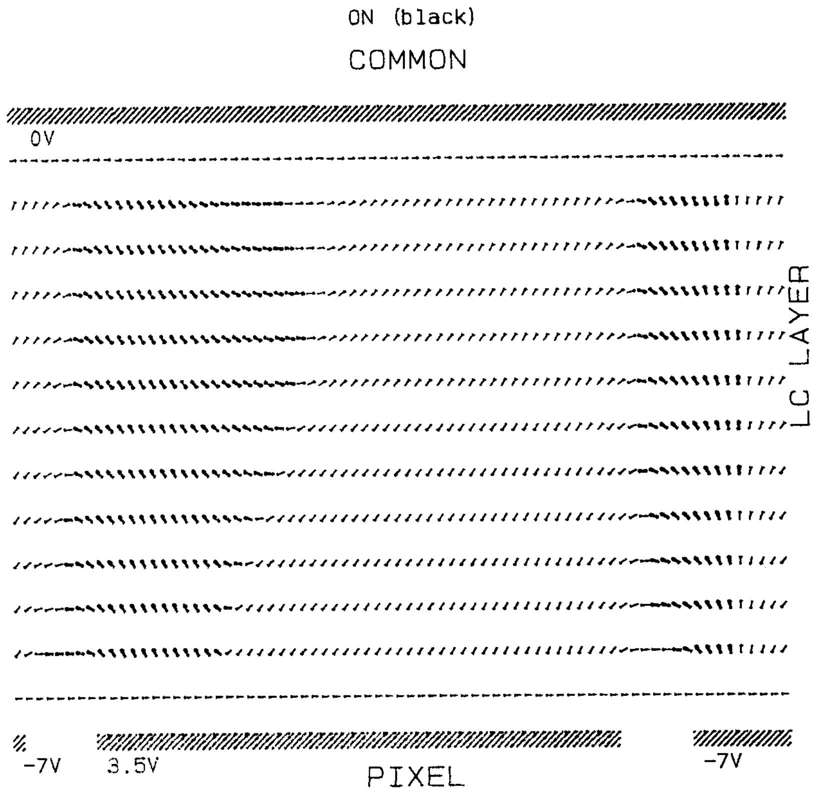

Figure 12. Simulation result at $T = 50\,\mathrm{ms}$, $K = 5 \times 10^{-12}\,\mathrm{N}$, $\Delta\varepsilon = 8$.

in figures 12 and 13. These figures 12 and 13 respectively correspond to figures 9 and 4 which show the results with $\Delta\varepsilon = 8$ and $K = 1{\cdot}5 \times 10^{-11}\,\mathrm{N}$.

In both cases, dielectric anisotropy has the same value, so that the initially induced reverse tilt domain has the same size. However, in the case that the liquid crystal has a small elastic constant, the director disturbance, which is caused by the field between buslines and pixel electrode, can easily grow. Therefore, a large reverse tilt domain can grow on the left-hand side of the pixel electrode, after a voltage greater than V_{TH} is applied to the pixel electrode.

6. Discussion

The above results show that the disclination location on the pixel electrode depends on the dielectric anisotropy ($\Delta\varepsilon$) and elastic constant (K) for the liquid crystal, which also determine the threshold voltage for the TN mode. This threshold voltage is given as

$$V_{TH} = \pi\sqrt{(K/\varepsilon_0\Delta\varepsilon)}.$$

A large dielectric anisotropy or small elastic constant leads to a low threshold voltage and large reverse tilt domain on the left-hand side of a pixel electrode.

To obtain a TFT-LCD with high contrast ratio, the light leakage caused by this disclination must be hidden behind a black matrix layer. The simplest black matrix is shown in figure 14. This black matrix layer makes the pixel aperture ratio small. To

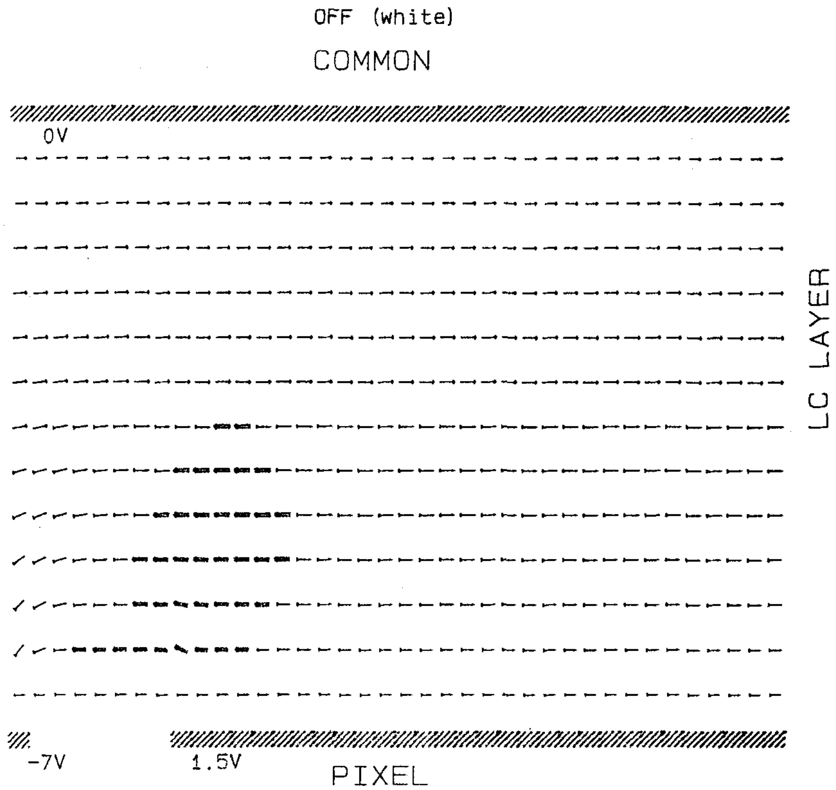

Figure 13. Simulation result at $T = 0.5\,\mathrm{ms}$, $K = 5 \times 10^{-12}\,\mathrm{N}$, $\Delta\varepsilon = 8$.

obtain a large pixel aperture ratio, this light leakage should locate closely on the pixel electrode edge.

This result shows that, with respect to the disclination location, a liquid crystal material with a small dielectric anisotropy and large elastic constant should be chosen.

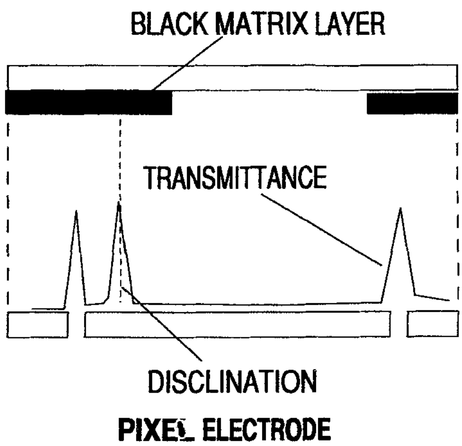

Figure 14. Black matrix configuration to mask the light leakage caused by the disclination.

7. Conclusion

A two dimensional liquid crystal simulator was developed, whose electrode configuration corresponds to that in TFT-LCDs. Results indicate that the field between the busline and pixel electrode makes the reverse tilt domain. A small dielectric anisotropy and large elastic constant make this reverse tilt domain small, and lead to a disclination location close to the pixel electrode edge, which results in a high aperture ratio being obtained.

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