Simulation Study on the Relationship Between Flicker Phenomena and Interface Polarization in Fringe-Field Switching Liquid Crystal Display

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ABSTRACT

Flicker phenomena in fringe-field switching liquid crystal displays (FFS-LCDs) were studied by finite element method simulations of the transport phenomena of ions, flexoelectric effect, and interfacial polarization. It was found that the influential cause of the flicker phenomena is the charge accumulated at the interface between LC and polyimide material.

1 Introduction

The fringe-field switching (FFS) mode[1] is used in smartphones and other high-quality liquid crystal displays (LCDs) because of its advantages, such as low-voltage drive, wide viewing angle, and high transmittance.

However, the FFS mode is prone to defects. Display defects in FFS-LCDs may be classified into two categories: display defects related to “orientation factors” and those related to “electrical factors.” Defects due to orientation result from the instability of the alignment axis. This instability of the alignment axis is caused by the insufficient anchoring force of the alignment film (made from polyimide (PI)) material due to plastic deformation during driving, resulting in a deviation from the initial alignment axis. The anchoring force is attributed to the van der Waals interactions between the LC and the PI molecules. However, display defects caused by electrical factors remain to be clarified in detail, and this study aims to elucidate them.

A structural feature of FFS-LCD is the insulating layer between the slit-shaped pixel electrode (PIX) and the common electrode (COM), which is generally composed of a nitride (SiNx) film and is structurally more complex than a vertical alignment (VA)-LCD[2], twisted nematic (TN)-LCD[3], or in-plane switching (IPS)-LCD[4]. The existence of this insulating layer is believed to be the cause of the electrical polarization; however, the detailed cause-and-effect relationship is not known. We studied these issues using a finite element method (FEM) simulation.

1.1 Flicker Phenomena and Other Issues

Display defects caused by electrical polarization are often manifested as flicker phenomena[5-8]. The flicker phenomena are caused by the modulation of transmitted light in synchrony with the frequency of the LC drive voltage and disturb viewing experience.

As shown in Fig.1, flicker phenomena can be classified into two types: flicker with the same period as the drive voltage (*type-A*), and flicker with half the period (*type-B*).

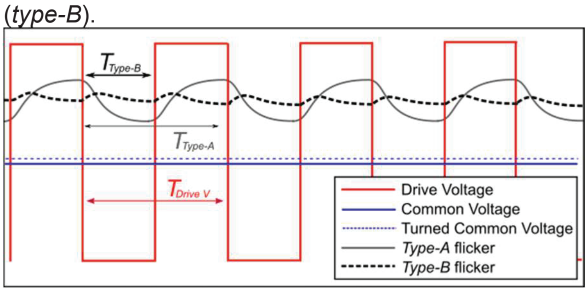

Fig. 1 Drive voltage, common voltage, turned common voltage and flicker types.

Type-A flicker is minimized by tuning the offset voltage applied to the COM during the final LCD manufacturing process. This offset voltage is called the flicker-minimized voltage, and is set according to the manufacturer. *Type-B* flicker cannot be tuned by the offset voltage. In many cases, *type-B* flicker is smaller than *type-A* flicker; thus, the problem becomes apparent when minimizing *type-A* flicker. These differences suggest that *type-A* flicker occurs when there is a bias potential in the LC layer, whereas *type-B* is the common phenomenon that responds to both the + and - frames of the drive voltage. Therefore, the causes of these two types of flicker phenomena differ.

Some of the specific problems associated with flickers include the following: Flicker phenomenon

(1) that occurs as soon as the drive starts.
(2) in which minimized flicker reappears during driving voltage.
(3) in which the minimizing voltage differs depending on the driving voltage.

These flicker phenomena also depend on backlight intensity and temperature, suggesting that the causes are complex.

Many of these problems are unique to FFS-LCDs; they do not occur in other LCD drive modes (TN, VA, IPS, etc.). Several studies have shown that flicker phenomena are caused by the flexoelectric effect[6,9] of the LC in FFS-LCDs and ions[10,11] in the LC material in other LCD modes. However, it is difficult to explain all the aforementioned flicker phenomena using this concept. Contrarily, because these flicker phenomena frequently occur depending on the combination of PI and LC materials, the interface between LC and PI materials is thought to be affected, but there are few research reports on this hypothesis. We studied and reported the relationship between flicker phenomena and electrical properties resulting from the resistivity and dielectric constant of LC and PI materials in FFS-LCDs[8,12]. However, our previous studies have not comprehensively examined the flexoelectric effect. In this study, we comprehensively studied the effects of both material properties and flexoelectric effects in the same simulation environment as our earlier studies and attempted to elucidate the phenomena of electrical display defects in FFS-LCDs.

2 Simulation method

FEM simulations were performed using COMSOL Multiphysics to study the relationship between polarization and flicker phenomena in FFS-LCDs. In addition to the basic functions of COMSOL, coupled simulations with the AC/DC and the Electrochemistry modules were performed. To reduce the computational load, a two-dimensional simulation was performed with periodic boundary conditions, considering the symmetry of the structure. The equations of motion for the LCs, electrostatic fields, and transport equations for the ions were solved in combination.

Phenomena such as the transport of ions in the LC and interface between LC and PI materials are considered to be common phenomena in all LCDs. Therefore, we first studied the cyclic voltammetry and dielectric loss of the counter electrode structure. The obtained transport phenomena model and parameters were then applied to the simulation of the FFS-LCD structures.

2.1 Electrostatic field

The dominant equation for the electrostatic potential in an FPD is the Poisson–Boltzmann equation.

$$\mathbf{E} = -\nabla V$$
$$\nabla \cdot (\varepsilon_0 \hat{\varepsilon}_r \mathbf{E} + \mathbf{P}_{\mathrm{Flexo}}) = \rho_V$$

2.2 Interface

The Butler–Volmer type charge and current density was adopted because an electric double layer is generated at the interface where the materials contact each other owing to the difference in potential and dielectric constant.

$$\rho_V [\mathrm{C/m^3}] = F\left(z_1 c_1 \exp\left(\frac{-z_1 e \Delta V}{k_B T}\right) + z_2 c_2 \exp\left(\frac{-z_2 e \Delta V}{k_B T}\right)\right)$$

$$i_{\mathrm{interafce}} [\mathrm{A/m^2}] = -Fk\left(c_1 \exp\left(\frac{-\alpha n_i F \eta}{RT}\right) - c_2 \exp\left(\frac{(1-\alpha) n_i F \eta}{RT}\right)\right)$$

2.3 Transport equation

The transport properties of charged ions within a material are described by the Nernst–Planck equation.

$$\mathbf{N}_i = -D_i \nabla c_i + z_i u_i F c_i (-\nabla V)$$
$$J = F \sum_i z_i \mathbf{N}_i$$

2.4 Equation of LC motion

The equation of motion for a two-dimensional LC, including the flexoelectric effect, was derived.

$$f_{LC} = \frac{1}{2} K_{11} (\nabla \cdot \mathbf{n}_{LC})^2 + \frac{1}{2} K_{22} (\mathbf{n}_{LC} \cdot \nabla \times \mathbf{n}_{LC})^2 + \frac{1}{2} K_{33} (\mathbf{n}_{LC} \times (\nabla \times \mathbf{n}_{LC}))^2$$

$$f_E = -\frac{1}{2} \varepsilon_\perp \mathbf{E}^2 - \frac{1}{2} \Delta\varepsilon (\mathbf{n}_{LC} \cdot \mathbf{E})^2$$

$$f_{Flexo} = -[e_{11} \mathbf{n}_{LC} (\nabla \cdot \mathbf{n}_{LC}) + e_{33} \mathbf{n}_{LC} \times (\nabla \times \mathbf{n}_{LC})] \cdot \mathbf{E}$$

3 Results

First, the influence of LC and PI materials on the FFS-LCD was discussed. Next, the influence of the flexoelectric effect was examined.

Fig.2 shows the cross-sectional profiles of the electric potential and polarization density in the FFS-LCD when there is no potential difference between the PIX and COM. These results indicate that the DC bias potentials and polarization caused by the electric double layer in the interface region were generated in the LC layer.

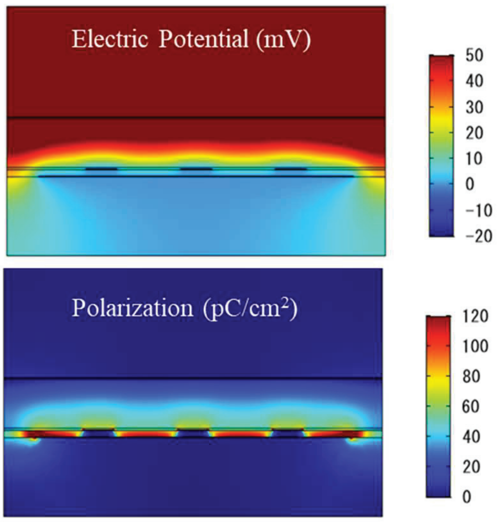

Fig. 2 Electric potential and polarization density in the FFS-LCD when potential difference between PIX and COM is zero.

The bias potential generated in the LC layer acts as an offset to the drive voltage, causing the transmitted light to fluctuate periodically in synchrony with the drive voltage. This means that even if there is no offset voltage in the drive voltage by the TFT drive, the offset voltage acts on the LC layer depending on the LC and PI materials; this is one cause of *type-A* flicker. The period of flickering owing to such bias potentials is same the period of the drive voltage. The polarization generated causes *type-B* flicker.

Fig. 3 shows a snapshot of the total and flexoelectric polarization densities when the TFT drive was simulated. The polarization owing to the flexoelectric effect was small.

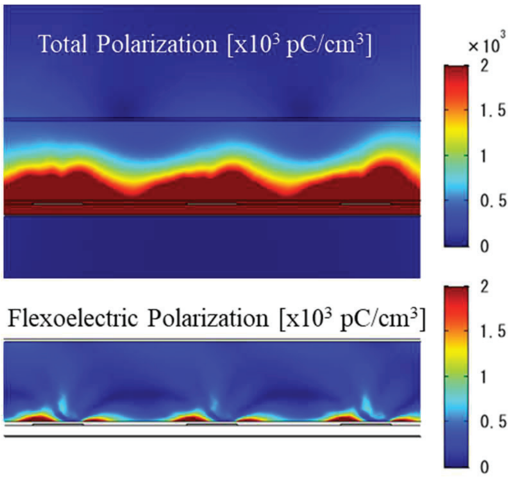

Fig. 3 Total and flexoelectric polarization densities on TFT drive simulation.

4 Discussion

Considering the electrical properties of the FFS-LCD, there are three characteristic electrical paths, as shown in Fig. 4.

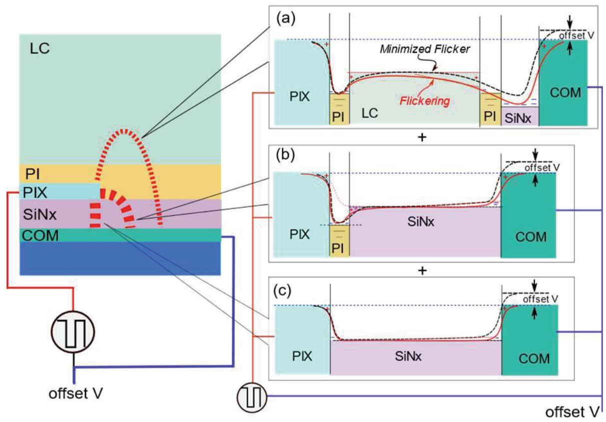

Fig. 4 Possible electric paths due to the electric properties of FFS-LCD.
(a) PIX - PI - LC - PI - SiNx – COM
(b) PIX - PI - SiNx- COM
(c) PIX - SiNx – COM

Particularly in the vicinity of the PIX edge, these paths were mixed, and the electrical bias was more complex than in other drive modes.

These composite influences resulted in a concentration of polarization density and charge accumulation in the FFS-LCD, as shown in the simulation results. The biases generated in the electrical path were not individually cancelled, suggesting a recurrence of flickering. Flicker-minimizing operations merely minimize the level of flicker, rather than canceling the bias components that occur in these electrical paths individually. These electrical biases suggest that the flicker is present from the initial stage of driving, or that it occurs during continuous driving. This phenomenon is known as flicker shift. Therefore, it is believed that the structural characteristics of FFS-LCDs cause complex interfacial potential and polarization, resulting in flickering.

5 Conclusions

We studied the flicker phenomena in FFS-LCDs by simulation, considering both the interfacial properties and flexoelectric effects. The relationship between the structural characteristics of the FFS-LCDs and the flicker phenomena, and the electrical double layer at the interface caused by the LC and PI material properties was discussed. The results showed that the charge accumulated at the interface acts as an offset voltage to the drive voltage, causing flicker.

The polarization due to the flexoelectric effect was found to be smaller than the interfacial polarization due to the influence of the LC and PI materials. Therefore, to determine the flexoelectric coefficient experimentally, it is essential to fully consider the interfacial polarization.

To improve the flicker problem, which causes LCD defects, it is effective to first overcome the interfacial potential and polarization and then improve the flicker caused by the flexoelectric effect.

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