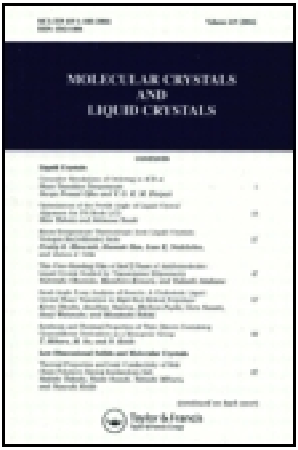

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A New Measurement Method for Ion Density in TFT-LCD Panels

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A New Measurement Method for Ion Density in TFT-LCD Panels

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A novel measurement method has been developed to optically measure ion density in TFT-LCD panels. We investigated the optical response of twisted-nematic (TN) cells when ions were transported by applying an alternating electric field. A characteristic flickering of transmitted light was observed when a rectangular voltage with a low frequency of 1 Hz was applied to the cells. A peak in light intensity was observed during voltage application. Its height was found to be related to ion density in a linear way. This density was measured by using the transient current technique. We conclude that ion density can be determined by measuring optical response.

Keywords: ion; twisted nematic; optical response; flicker

1. INTRODUCTION

A thin-film-transistor liquid-crystal display (TFT-LCD) offers high-quality images. Unfortunately, defects sometimes occur in the production process.

Ion impurity can cause non-uniform contrast because ions have an influence on the control voltage of the liquid crystal layer. As a result, it is necessary to measure the ion density of the LCD quickly to find the cause of defects.

Ion density has been measured in LC cells by using a transient current technique [1-5]. This electrical measurement technique is suitable for simple LC cells. Unfortunately, applying this technique to actual TFT-LCDs is difficult. Consequently, a chemical analysis technique is often used in defect analysis. This technique has some disadvantages. Sample preparation requires expertise and takes a great deal of time for a destruction of the LCD and an extraction from LC to water. In addition, neutral compounds are sometimes recognized as ions because of dissociation in sample water. To overcome these drawbacks, technique for measuring ion density in TFT-LCDs is necessary.

We previously noticed an optical response influenced by ion transportation because LC reorientation was expected following a changing in the electric field caused by ion transportation. A characteristic flickering of transmitted light was observed when a rectangular voltage was applied to TN cells with ions. This same flicker was observed in an actual TFT-LCD with a contrast defect. This characteristic response of transmitted light is the focus of this work.

2. EXPERIMENT

TN cells containing ions were prepared for our experiments. Each TN cell was composed of two glass substrates, each with an indium-tin-oxide electrode and a 40-nm-thick polyimide alignment layer on its surface. The electrodes were 1 cm^2, and the cell gap was 5 μm. The polyimide alignment layers were rubbed to orient the NLC molecules to a 90° twist angle. An NLC mixture of fluorinate was injected into the cells.

The ion densities and the voltage holding ratios (VHR) of the TN cells were measured. The ion densities were measured from the current responding to a triangular voltage (±10 V, 0.1 Hz) at room temperature, using our measurement system MTR-1 (Toyo Corp.). The VHR measurement was performed by using a function generator (AG4100,Yokogawa) and an impedance converter (Micronix MZ101). A rectangular voltage output from the function generator was turned into a pulse-rectangular wave by using the impedance converter as a switching component. The rectangular wave had a frequency of 30 Hz and an amplitude of 5 V. The control voltage applied to the impedance converter was also generated by the function generator. The time in the low impedance state (closed switch) was 60 μs, and that of the high impedance state (opened switch) was 16.66 ms. The voltages of the cells were measured by using a digital oscilloscope (DL4200 Yokogawa).

The optical responses to the applied ±2.3-V AC rectangular voltage of 1 Hz were observed. The TN cells were located between two polarizing plates arranged with crossed nicols (normally white). The light intensity through each TN cell from a halogen lamp was measured by using a photometer. The light intensity was transformed to relative transmittance. Light intensity was regarded as 0 % when a voltage of ±5 V was applied with a 30-Hz frequency. A transmittance of 100 % corresponds to the light intensity when no voltage was applied to the TN cell. The amplitude of the optical response was compared with the ion density from the electric measurements.

The optical response of an actual LCD was also observed in an area with a contrast defect. Sources and drains were always connected by gates with DC voltage applied in TFTs. The AC rectangular voltage was applied to drain lines with a frequency of 1 Hz. Common electrodes were grounded.

3. SIMULATION

A theoretical simulation was performed for the electro-optical responses observed in the experiment. The calculated system was a one-dimensional model of the TN cell, as shown in Fig. 1. The director of NLC is expressed as **n** = (sinθcosϕ, sinθsinϕ, cosθ). The free energy f of TNLC can be written as

$$f = \frac{1}{2}\left[K_{11}(div\mathbf{n})^2 + K_{22}(\mathbf{n}\cdot rot\mathbf{n} + q)^2 + K_{33}(\mathbf{n}\times rot\mathbf{n})^2 - \mathbf{D}\cdot\mathbf{E}\right]$$

where K_{11}, K_{22} and K_{33} are the Flank elastic constants, q is the helical wavevector (2π/P), **E** is the electric field, and **D** is the electric displacement [6]. This equation and the Euler-Lagrange equation provide torque balance equations for $\partial\theta/\partial t$ and $\partial\phi/\partial t$. The electric field is given by Gauss' theorem. The distribution of ions was calculated by using the continuous current equation which contains a diffusion term and the dependence of the mobility on the director tilt. Transmittance was calculated by using Johns' matrix. The numerical calculations were carried out by dividing the LC layer into 100 slabs and the polyimide layers into 10 slabs.

Some assumptions were necessary in the calculations. The quantity of positive ions and negative ions are the same. We assumed that they originated from the dissociation of a large organic acid salt, like sodium stearate ($CH_3(CH_2)_{16}CO_2Na$), introduced to the LC layer. We also assumed that the positive ions (considered small) could pass through the interface of the alignment and LC layers. The mobility in the LC layer was set at 5 x 10^{-6} cm^2/Vs, and that of the alignment layer was set at 8 x 10^{-8} cm^2/Vs. Negative ions were assumed to exist only in the LC layer because their size prevents them from passing through the interface.

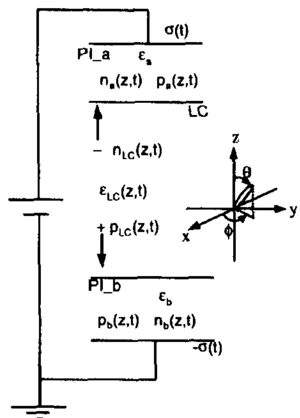

Fig. 1. Cross-sectional view of TN cell.

Their mobility was set at 5 x 10^{-9} cm^2/Vs.

4. RESULTS AND DISCUSSION

The ion densities and VHRs of the TN cells is shown in Fig. 2. The VHR decreased as the ion density increased. A typical electro-optical response is shown in Fig. 3. The transmitted light flickers according to changes in the

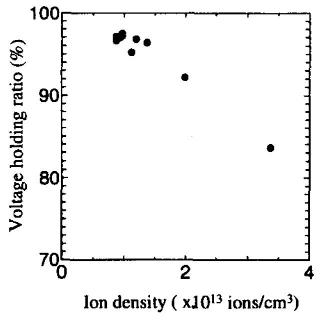

Fig. 2. Measured VHRs and ion densities.

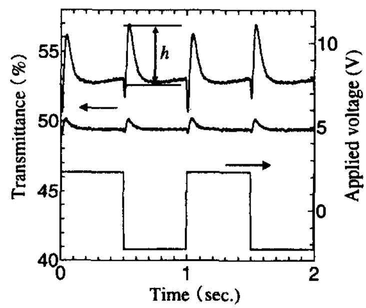

Fig. 3. Observed optical response of TN cells.

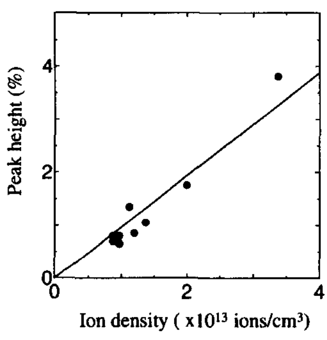

Fig. 4. Dependence of peak height on ion density.

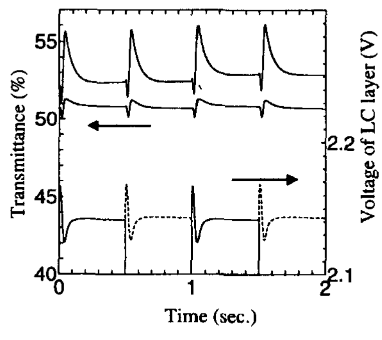

Fig. 5. Calculated optical response of TN cells.

electric field, which is a result of the ion transport. After the polarity of the applied voltage was reversed, the transmittance dipped and then formed a large peak. The peak height observed in the cell with the high ion density (the upper line, 3.4×10^{13}ions/cm^3) is higher than that in the cell with the low ion density (the lower line, 0.9×10^{13}ions/cm^3). Figure 4 shows the relationship between the peak height and ion density. The peak height seems to be proportional to ion density. As a result, we find that ion density can be estimated based on the peak height of the light flicker when a rectangular voltage with a low frequency is applied to the TN cell.

The simulated response closely matches the experimental one as shown in Fig. 5. The upper curves show the transmittance responding to an applied voltage of ± 2.2V with a frequency of 1 Hz. Both the positive and negative ion densities are set at 4.0 x 10^{13} ions/cm^3 for the cell with the high ion density. In the case of low ion density, the ion density is set at 1.0 x 10^{13} ions/cm^3. The lower line shows the calculated voltage working on the LC layer. The solid line shows the voltage when positive voltage was applied, and the broken line shows the voltage when negative voltage was applied to a TN cell. The transmittance declined rapidly after the polarization of the applied voltage was switched, it then rises, and decreases again. This matches the observed results. The voltage working on the LC layer is closely synchronized with the transmittance. The optical response is considered a result of LC reorientation following the change in voltage. The change in voltage can be explained as a result of ion transportation.

Figure 6 shows ion density, electric field and director angle distribution in the calculated cell. All the positive ions are near the interface of the electrode and polyimide (PI) layers just before the polarities of the applied voltage are switched. The positive ion starts to move toward the opposite electrode after the polarity change (Fig. 6. (a) to (b)). This ion movement causes the electric field of the PI layer to decrease until the ions pass through the interface, so that the voltage of the LC layer increases. This voltage increase causes greater tilt in the LC director. The transmittance is

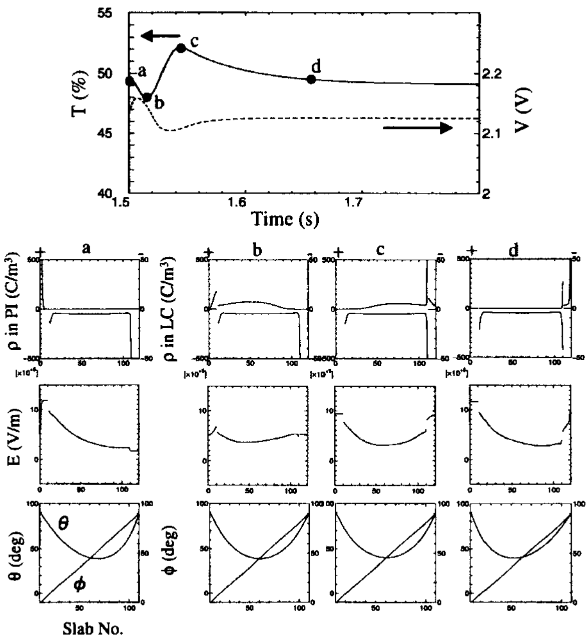

Fig. 6. Calculated distribution of ion density (ρ), electric field (E) and director (polar angle (θ), azimuth angle (ϕ)).

reduced. Next, the positive ions enter and move within the LC layer (Fig. 6. (b) to (c)). The electric field in the LC layer decreases, and the LC director lies flat on the substrate. The transmittance increases. Then, positive ions pass through the opposite interface between the LC layer and the PI layer, and thus reaching the opposite electrode (Fig. 6. (c) to (d)). The electric field of the LC layer increases, and the opposite PI layer decreases. The director tilts again, and the transmittance falls.

The optical peak height was also calculated for the ion density. Figure 7 shows the relationship between the optical peak height and the positive ion density calculated based on the same model. The observed results well match the calculation.

This same optical response was observed in a contrast defect area in an actual LCD. Figure 8 shows the optical responses in the defect and the normal areas. The response in the defect area is similar to the experimental results involving ions in TN cells. The mobile ion density was estimated to be about 1.0 x 10^{13} ions/cm^3 based on the relationship shown in Fig. 7., ion parameters were assumed to be nearly the same as in the experimental TN cell.

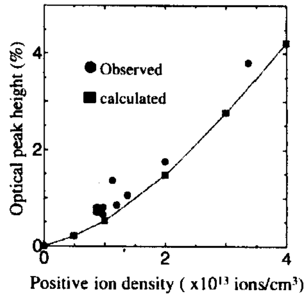

Fig. 7. Calculated dependence of optical response on ion density.

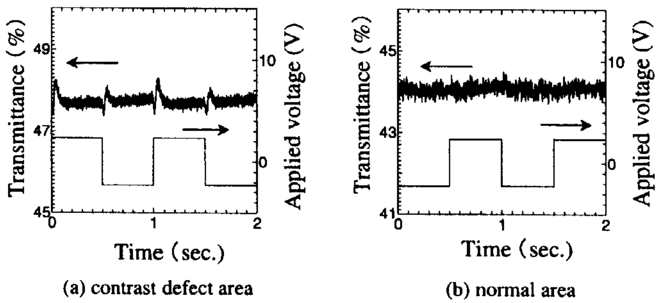

Fig. 8. Optical response observed in actual LCD.

5. CONCLUSION

We investigated the optical response of twisted-nematic (TN) cells when ions are transported. A characteristic flickering of transmitted light was observed when a rectangular voltage was applied to cells with a low frequency of 1 Hz. A peak in light intensity was observed when a voltage was applied. The height of the peak had a nearly linear relationship to ion density in the TN cell. Ion density was also measured in an actual TFT-LCD. We conclude that ion density can be estimated by measuring optical response. A new optical measurement method was developed for ion density in TFT-LCD panels.

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