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A New Transflective Geometry of Low Twisted Nematic Liquid Crystal Display having a Single Cell Gap

Jinyool Kim[**], **Dong-Woo Kim**[**], **Chang-Jae Yu**[**], **and Sin-Doo Lee**[*]

Abstract

We have developed a new type of transflective liquid crystal display (LCD) with a single cell gap and a single LC mode. In our transflective configuration, a single LC mode of a 60° twisted nematic LC was used for both transmissive and reflective applications. The measured electro-optic characteristics of our transflective LC cell agree well with numerical simulation results. Moreover, the transmittance was found to show similar behavior to the reflectance.

Keywords : transflective liquid crystal display, liquid crystal, low twisted nematic, fast response

1. Introduction

Transflective LCDs have begun to play a significant role in mobile applications since they show good optical performances in both indoor and outdoor and low power consumption [1~3]. The pixels in transflective displays are largely divided into two regions, i.e., transmissive and reflective parts. A conventional structure of the transflective LCD contains a multi-gap design due to the optical path difference between the transmissive and reflective parts [2, 3]. Although the transflective LCD with a multi-gap shows good optical characteristics, the multi-gap fabrication process results in high cost and low yield in manufacturing [4]. In recent years, an approach to a hybrid LC configuration with a single gap has been taken because of the simple manufacturing process [5, 6]. The optical path difference in this configuration was compensated by using two kinds of LC modes in the multi-mode transflective display. However, the different LC modes inevitably involves different responses of the LC to an applied voltage such as the voltage-transmittance and the threshold voltage. This in turn means that, different driving schemes must be employed for the transmissive and reflective parts. In this work, we propose a new design for the transflective LCD, having a single cell gap and a single LC mode, in a single driving scheme [7]. The measured electro-optic (EO) performances are presented below along with a comparison with the numerical simulations.

2. Experiments

The transflective LC cell was made using two glass substrates coated with indium-tin-oxide. The alignment layer of AL1051 (Japan Synthetic Rubber Co., Japan) was coated on the inner surfaces of the substrates and rubbed uni-directionally to produce uniform planar alignment. The two substrates were assembled to make an angle of 60° between the two rubbing directions. The cell thickness was maintained using glass spacers with a thickness of 1.8 μm. The MLC6012 (Merck) doped with S-811 was injected into the cell by capillary action at room temperature. The reflector used has two regions, i.e., transmissive and reflective parts. The reflective part was deposited with aluminium (Al) and a quarter wave film was directly attached onto the Al layer. The reflector was attached on one side of the LTN cell and two polarizers were attached to both sides of the LTN cell as shown in Fig. 1. The transmittance and the reflectance through this transflective LC cell of a He-Ne laser at 633 nm were measured as a function of the applied voltage from 0 to 10 V. The response times were measured using a square wave voltage of 50 Hz.

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[*] Members, KIDS; [**] Student Member, KIDS.
Corresponding Author : Sin-Doo Lee
School of Electrical Engineering, Seoul National University, Kwanak P. O. Box 34, Seoul 151-742, Korea.
E-mail : sidlee@plaza.snu.ac.kr **Tel** : +2 880-1823 **Fax** : +2 874-9769

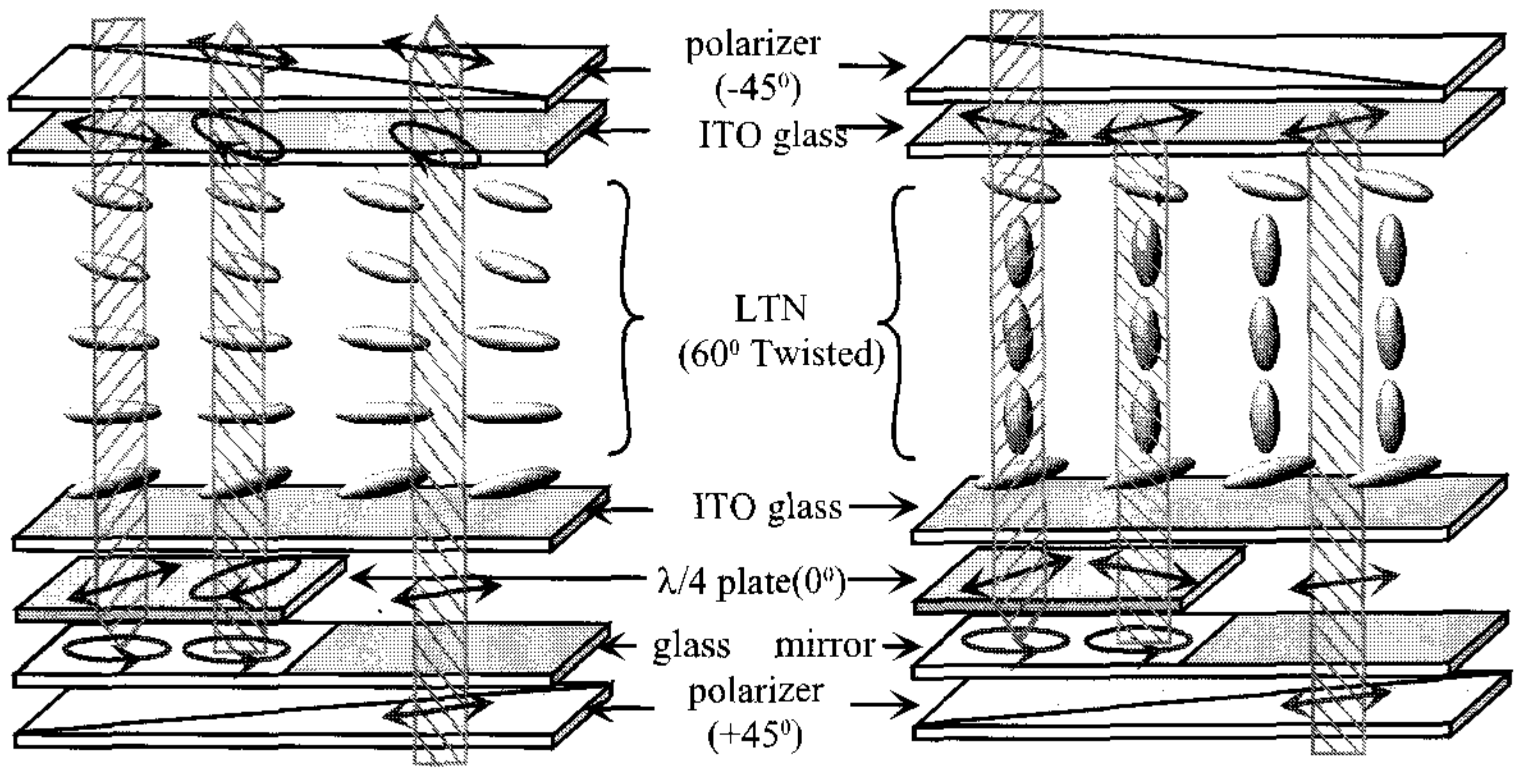
3. Results and Discussion

The newly proposed transflective LC cell consists of a transmissive part and a reflective part. As shown in Fig. 1, the transmissive part is composed of two polarizers, a low twisted (60°-twisted) nematic LC (LTN) cell. The operation principle is basically identical to a conventional TN LCD case. The reflective part is composed of a polarizer, a 60°-TN LC cell, a quarter wave plate, and a reflector. One of the advantages of the proposed transflective LC cell is that it involves a simple manufacturing process because a single LC layer is used for both transmissive and reflective parts. This means that there requires no additional processes to be conducted in cell fabrication.

We used a cell gap with a thickness of 1.8 µm. This gap is much smaller than that for the Gooch-Tarry first minimum (3.4 µm) that was evaluated from the relationship $\sqrt{3}\,\lambda\phi/\pi\Delta n$, where λ, ϕ and Δn are the wavelength of the incident light, the phase retardation, and the birefringence, respectively. In this relatively thin cell configuration, our LC cell shares some common features with the mixed mode twisted nematic (MTN) mode [8]. In the MTN mode, the twist angle is usually smaller than 45° for using both the polarization guiding effect and the optical retardation for reflective-type applications.

In this study, the twist angle is optimized for both the reflective and transmissive parts and only the guiding effect in the LTN cell is considered. The operation principle of our transflective LCD is described in Fig. 1. In the transmissive part, an input light from a backlight unit is converted into a linearly polarized light by an input polarizer. The polarization state of the input light is rotated through the LTN layer in the field-off state, and then, the light is transmitted through the output polarizer. No polarization rotation occurs under applied voltage. In the reflective part, an input light from the front panel is converted into a linearly polarized light. The polarization state of the input light is rotated through the LTN layer. Due to the mismatch between the output polarization direction and the optic axis of a quarter wave plate, the outcoming light emerging from the quarter wave plate is elliptically polarized. In addition, the phase of light is changed by π due to the reflector and the emitted light is guided by the LTN layer and transmitted through the front polarizer. Accordingly, a bright state is obtained under no applied voltage. Under applied voltage, the wave guiding effect normally becomes interrupted. Above the saturation voltage, the LTN layer produces no optical retardation. In our experiment, the polarization of the input undergoes only $\lambda/2$ of the optical retardation due to the quarter wave plate and the reflector. Thus, the emitted light is blocked by the front polarizer and a dark state is obtained.

We first performed numerical simulations to obtain the EO characteristics of several transflective LC cells within the Extended Jones matrix formalism [9]. The material parameters used for numerical simulations were the elastic constants $K_1 = 11.6\times10^{-12}$ N, $K_2 = 5.5\times10^{-12}$ N, $K_3 = 16.1\times10^{-12}$ N, the ordinary refractive index $n_o = 1.4620 + 5682/\lambda^2$, the extraordinary refractive index $n_e = 1.5525 + 9523/\lambda^2$, the dielectric anisotropy $\varepsilon_a = 8.2$ and the rotational viscosity $\gamma_1 = 0.192$ Pa· sec. Here, λ is the wavelength of the incident light in nm. Fig. 2 shows the numerical results



(a) (b)

Fig. 1. Structure and operation principle of the proposed transflective LC cell having a single gap and the LTN mode: (a) a bright state (field-off) and (b) a dark state (field-on).

for three cases of different cell gaps. The gaps with thicknesses of 3.4 μm and 1.8 μm thick correspond to the Gooch-Tarry first minimum and the λ/4 condition, respectively. The magnitude of the birefringence larger than λ/4 produces an undesirable EO property which is a concave or a convex shape in the reflectance-voltage curve near the threshold voltage as shown in Fig. 2. In addition, the reflectance becomes quite different from the transmittance. Therefore, in our study, the cell gap was reduced to obtain similar or even identical EO characteristics in the two regions.

Next, we evaluated the transmittance as a function of the twist angle θ to determine an optimized twist angle in our transflective LC cell. The transmittance for an arbitrary twist angle in the normal TN cell was calculated by Ong [10]. The transmittance can be calculated as a function of the twist angle θ by substituting $\Phi_{ent} = \pi/2 - \theta$, $\Phi_{exit} = \theta$ into Ong's expression. The resultant transmittance is given by

$$T(\theta)=\sin^2\theta+\frac{\sin[2\theta\sqrt{1+u^2}]\sin 2\theta}{2\sqrt{1+u^2}}+\frac{\sin^2[\theta\sqrt{1+u^2}]\cos 2\theta}{1+u^2}, \quad (1)$$

where $u=(\pi d/\theta\lambda)(n_e/\sqrt{1+\omega\sin^2\theta_s}-n_o)$ with $\omega=(n_e/n_o)^2-1$, the cell gap d, and the pretilt angle θ_s. For the cell gap with a thickness of 1.8 μm, the transmittance $T(\theta)$ has a maximum at $\theta=45°$ and decreases as the twist angle deviates from $\theta=45°$. Although the twist angle of 45° is desirable for the transmittance itself, both the efficiency and the EO characteristics should be taken into account.

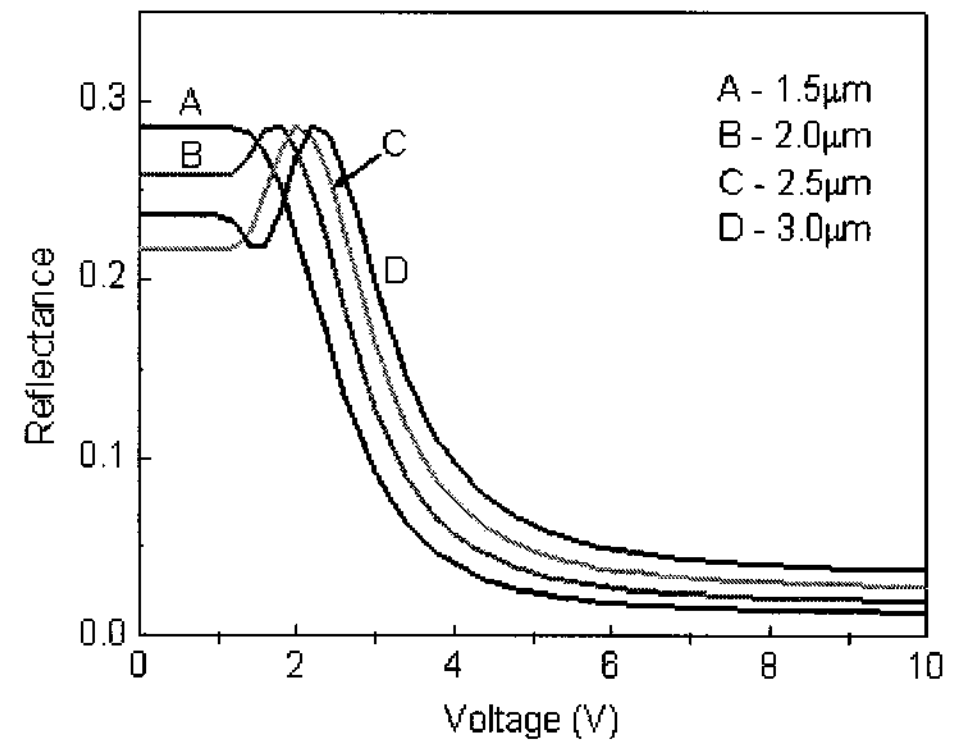
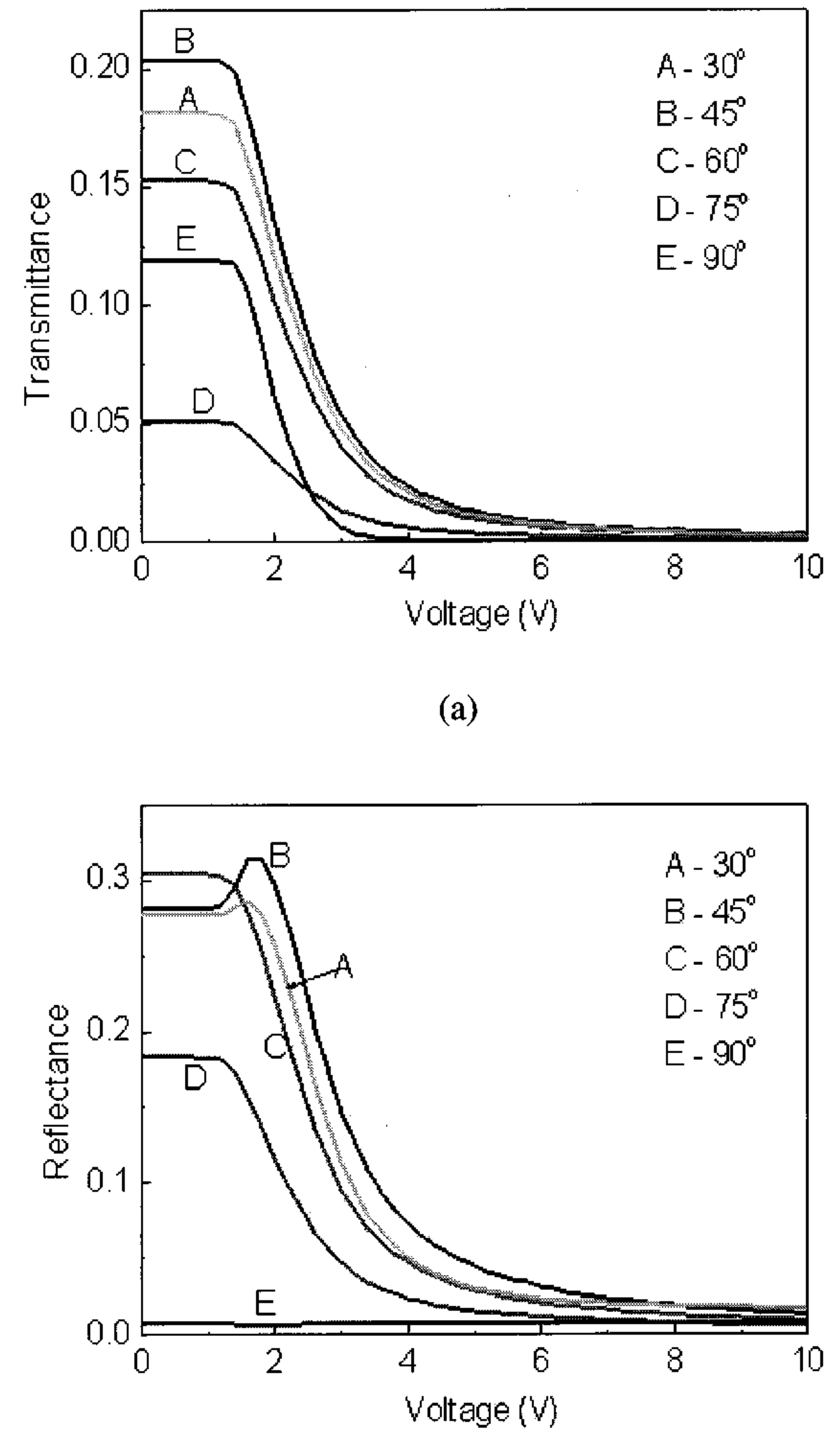


Fig. 2. EO characteristics of several transflective TN LC cells with different cell gaps. The lines A, B, C and D represent the reflectances of LC cell with cell gap 1.5 μm, 2.0 μm, 2.5 μm, and 3.0 μm, respectively.

The numerical results for five cases of different twist angles are shown in Fig. 3. The transmittances and reflectances of the five different twist angles; 30°, 45°, 60°, 75°, and 90°, are represented in Figs. 3(a) and (b), respectively. As shown in Fig. 3(a), the 45°-TN case has a maximum transmittance that, is consistent with Eq. (1). The reflectance in the LTN(30°- or 45°- twisted) cell has high efficiency but it exhibits an overshoot behavior near the Frederiks' threshold as shown in Fig. 3(b). Therefore, both the optical efficiency and the overshoot behavior of



(a)

(b)

Fig. 3. EO characteristics of several transflective TN LC cells with different twist angles. The lines A, B, C, D and E represent the optical intensities of LC cell having the twist angle 30°, 45°, 60°, 75°, and 90°, respectively: (a) The transmittances of transflective LC cells with different twist angles and (b) the reflectances of transflective LC cells with different twist angles.

the EO response should be considered for the reflectance. Since a transflective LC cell in a single driving scheme is desirable, the 30°- and the 45°-TN cells are not suitable because of the observed overshoot behavior. For the 60°- and the 75°- TN cells, the transmittance and the reflectance are similar to each other. The 60°-TN cell shows higher optical efficiency than the 75°-TN cell which is the reason why the 60°-TN cell was selected as the transflective LC cell to be used in this study. Further optimization of our 60°-TN cell was needed prior to use.

Fig. 4 shows the experimental EO results and numerical simulations for the 60°-TN transflective cell as a function of the applied field. The transmissive and reflective intensities were normalized to examine the essential features of the EO responses in both the transmissive and reflective regions. The open symbols and the lines represent the experimental results and the numerical simulations, respectively. As shown in Fig. 4, it is clear that the EO characteristics of the transmissive and the reflective parts were very similar to each other. Thus, a single driving scheme is applicable for our transflective LC cell. It should be noted that a small cell gap is desirable for improving the EO response time. The measured EO response times are shown in Fig. 5. The rising and falling times of the response were found to be 5.8 msec and 0.8 msec, respectively. This means the switching times are fast enough for video-rate applications.

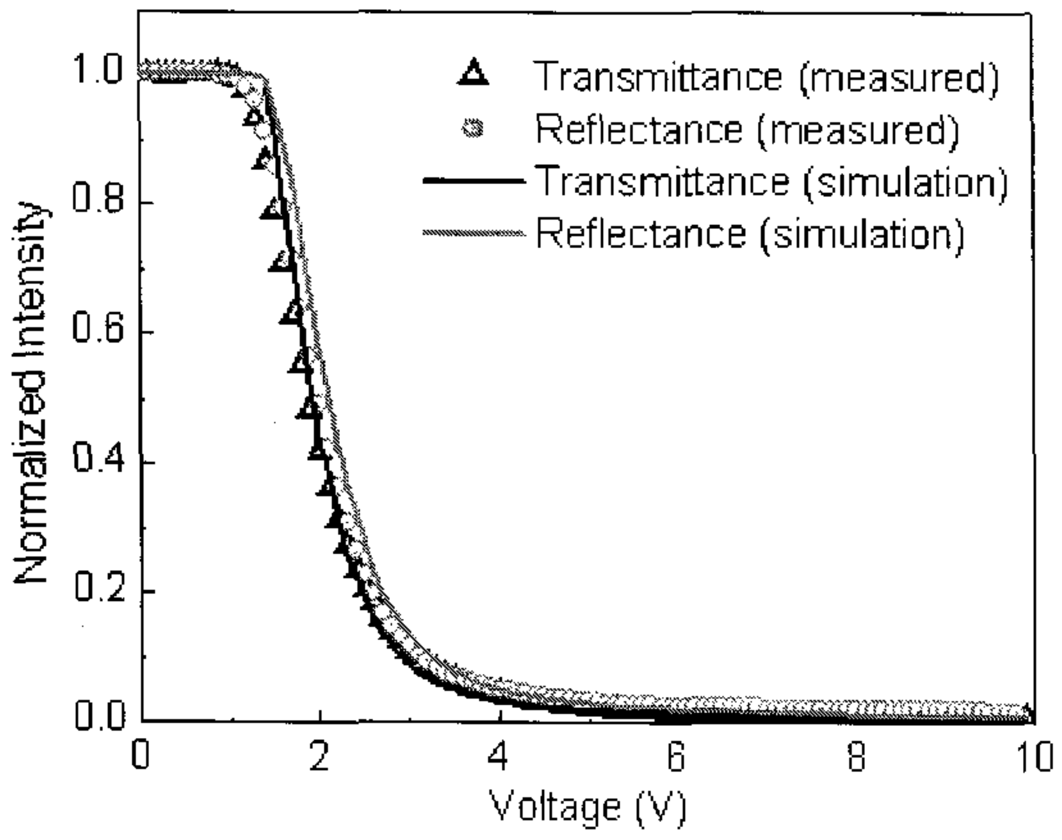


Fig. 4. EO characteristics of the proposed transflective TN LC cell. Open symbols and lines represent the experimental results and numerical simulations, respectively.

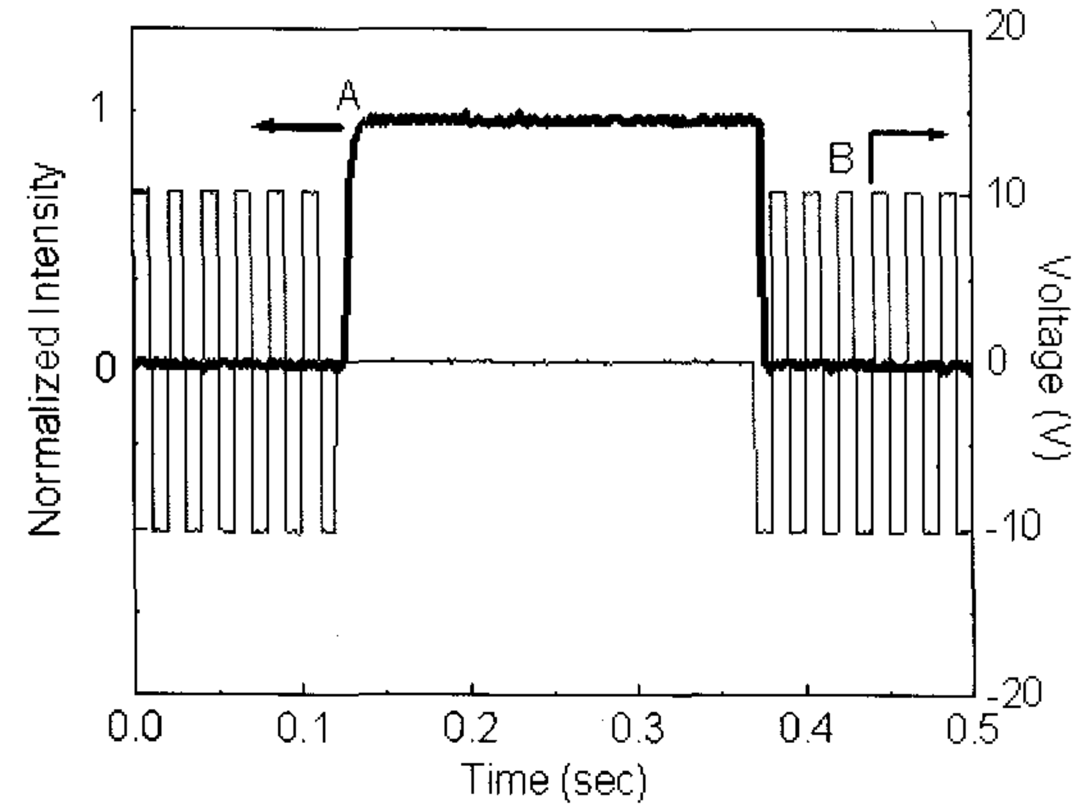


Fig. 5. EO response times of our transflective TN LC cell. The lines A and B are the normalized EO response and the pulse input, respectively.

4. Conclusions

We demonstrated a new design of a transflective LCD having a single cell gap and a single LC mode. The EO characteristics of the transmissive and the reflective parts were found to be quite similar, and thus a single driving scheme could be used. Due to the small cell gap, it was possible to obtain fast response times. Based on this study the new design of the transflective LCD is will contribute to the mobile LCD applications.

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