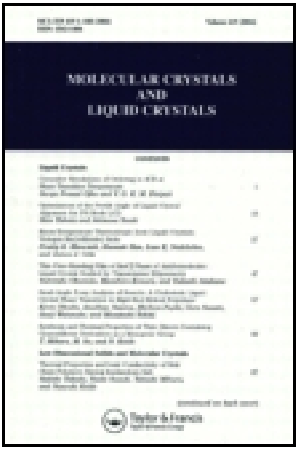

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A Transflective LCD Having a Patterned Retardation Layer for a Single Driving Scheme

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A Transflective LCD Having a Patterned Retardation Layer for a Single Driving Scheme

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We have developed a new transflective liquid crystal (LC) display with a single cell gap and a low twisted nematic (LTN) mode configuration. In order to obtain a single cell gap and a single LC mode, we make a patterned retardation layer having both the homeotropic and planar alignment in this display mode. The patterned retardation layer was made of a photo-polymerizable liquid crystalline material by applying single step patterning of a photo-masking technique. The electro-optic characteristics of the transmissive and reflective parts were nearly identical and thus a single driving scheme can be used.

Keywords: liquid crystal (LC); liquid crystal display (LCD); low twisted nematic (LTN); patterned retardation layer; photoalignment; transflective LCD

INTRODUCTION

The role of transflective liquid crystal displays (LCDs) is becoming more and more important because they show good visibility under both strong and weak lighting conditions while keeping superior performances such as portability, good readability, and low power consumption [1]. In general, a transflective LCD consists of two subpixels of the transmissive and reflective regions with a multi-gap design was used in a single pixel [2]. Although the transflective LCDs with a multi-gap have good optical performance, the multi-gap fabrication process results in high cost and low yield in manufacturing [3]. In recent years, various transflective

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LCDs with a single cell gap having two different modes, vertically aligned and hybrid aligned modes in two subpixels, were proposed [4,5]. The above existing multimode transflective LCDs were found to show high contrast ratio, wide viewing characteristics, and achromaticity. However, different LC modes inevitably involve different responses of the LC to an applied voltage such as the voltage-transmittance and the threshold voltage. Thus, the electro-optical (EO) disparity limits the image quality and different driving schemes must be employed for the transmissive and reflective parts. Also extra retardation layers should be laminated on the exterior of the above-mentioned display in order to deliver the desired optical performances [2–5].

In this work, we demonstrate a new design of a transflective LCD having a single cell gap and a single low twisted nematic (LTN) mode by adopting a patterned retardation layer. Due to same LC mode in both transmissive and reflective parts, the properties of the LC show uniform electrically controllable birefringence in the whole LC layer. The transmittance curve coincides well with the reflectance curve. Since the measured EO characteristics of two parts were found to be nearly identical, a single driving scheme can be used. Moreover, a patterned retardation layer was manufactured from photo-polymerizable liquid crystalline material [6] by one step patterning photoalignment method [7,8].

OPERATION PRINCIPLE

Figure 1 shows a schematic diagram of our transflective LC cell in a single cell gap and a single mode configuration with a patterned

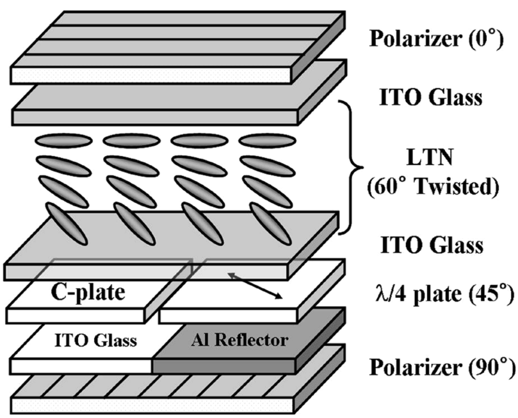
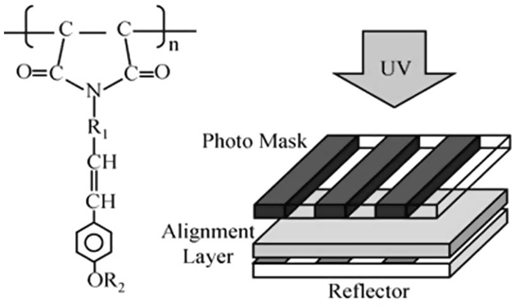


FIGURE 1 Schematic diagram of transflective LC cell in a single cell gap and a single LTN LC mode configuration with a patterned retardation layer.

retardation layer. In this single mode transflective LCD, the LC molecules are low twisted both in the transmissive region and the reflective region. A patterned retardation layer on the photoalignment layer, where two directions of the linearly polarized UV (LPUV) exposure exist with respect to the rear polarizers, are the C-plate layer in the transmissive region and a quarter wave plate in the reflective region [6]. In the transmissive part, an input light from a backlight unit is converted into a linearly polarized light by an input polarizer. The linearly polarized light passes through the vertical layer without experiencing any optical retardation. The polarization state of the input light is rotated through the LTN layer in the field-off state, and the light is then transmitted through the output polarizer. No polarization rotation occurs under an 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. The phase of light is changed by π due to the reflector. Thus, the outcoming light is guided in the LTN layer and is transmitted through the front polarizer. Accordingly, a bright state is obtained under no applied voltage. Under an applied voltage, the wave guiding effect becomes disturbed. Above a certain saturation voltage, the LTN layer produces no optical retardation. In this case, the polarization of the input undergoes only $\lambda/2$ of the optical retardation due to the quarter wave plate and the reflector. Thus, the outcoming light is blocked by the front polarizer and a dark state is obtained.

EXPERIMENTS

The transflective LC cell was made using two glass substrates deposited with indium-tin-oxide. The polyimide of AL1051 (Japan Synthetic Rubber Co., Japan) was coated on the inner surfaces of the substrates and imidized at 200°C for 1 hour. The polyimide film was rubbed unidirectionally to produce uniform planar alignment. The two substrates were assembled to make an angle of 60° between two rubbing directions. The cell thickness was maintained using glass spacers of 1.8 μm thick. The MLC6012 (Merck) doped with S-811 was injected into the cell by capillary action at room temperature. For the fabrication of the patterned retardation layer, photo-polymerizable liquid crystalline material LC242 (BASF) was used. The reflector used in this study has two regions, transmissive and reflective parts. Aluminum (Al) was deposited on the reflective part of the substrate.



(a) (b)

FIGURE 2 Fabrication process of a patterned retardation layer with UV treatments. (a) The structure of a side-chain type photo-polymer. Here, R_1 and R_2 represent CO and C_5H_{11}, respectively. (b) The single process of LPUV exposure scheme with photo-masking technique.

A photo-reactive polymer having the structure in Figure 2(a) was coated onto the reflector and baked at 150°C for 30 minute. For compensating the optical path difference, we fabricate a patterned retardation layer with a dummy layer and quarter wave plate (QWP) in the transmissive and reflective parts, respectively. The reflector was attached on one side of the LTN cell and two polarizers were attached to outer sides of the LTN cell.

For fabricating a patterned retardation layer, a photopolymer having photoreactive side chains was used as an alignment layer for the photo-polymerizable liquid crystalline material. As shown in Figure 2(a), the photoactive cinnamoyl group is attached to the polymaleimide backbone. As an alignment layer, this polymer induces homeotropic and planar LC alignment in the unexposed and the UV exposed areas, respectively. As shown in Figure 2(b), the UV light was illuminated on the photopolymer through a photomask. The photo-polymerizable liquid crystalline material was coated on the patterned layer and cured by an additional UV exposure. The photo-patterns on the photopolymer were transferred to the nematic networks. As a result, the retardation layer having both the homeotropic and planar alignment was produced as shown in Figure 3. The planar part shows a bright or a dark state depending on the optic axis with respect to one of the crossed polarizer as shown in Figure 3(a) and Figure 3(b), respectively. The measured phase retardation in the planar part using a photo-elastic modulation technique was about 1.6, corresponding to a QWP ($\pi/2$). The homeotropic part, in principle, shows a dark state in any direction of the optic axis under crossed polarizers. In our case, the phase retardation was

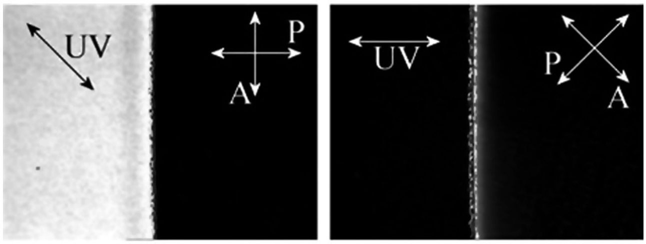


FIGURE 3 Microscopic texture of a patterned retardation layer on the glass without reflector in our transflective LC cell observed under crossed polarizer: (a) an angle of 0° and (b) 45° between the direction of retardation layer and the rear polarizer.

measured to be about 0.1, which is negligible for practical applications. Such nonzero phase retardation results in a very small difference between the homeotropic part in Figure 3(a) and that in Figure 3(b).

MEASUREMENTS AND SIMULATIONS

Our transflective LC cell has a transmissive part and a reflective part. As shown in Figure 1, the transmissive part is composed of two polarizers and a low twisted (60°-twisted) LC cell. The operation principle is basically identical to a conventional TN LCD. The reflective part is composed of a polarizer, a 60°-TN LC cell, a quarter wave plate, and a reflector. The fabrication process of our transflective LC cell is simple compared to the multi-gap case because a single LC mode is used for both transmissive and reflective parts. Therefore, no additional processes are needed in cell fabrication.

We used the cell gap of 1.8 μm thick. This gap is much smaller than that for the first minimum condition of 3.4 μm, given by the Gooch-Tarry criterion [9]. In this relatively thin geometry, our transflective LC cell shares some common features with the mixed-mode TN mode with a relatively low twist of 45° [10] where the polarization guiding effect and the optical retardation are used for reflective-type applications. In our case, the twist angle is optimized for both the reflective and transmissive parts and only the guiding effect is considered.

We performed numerical simulations to obtain the EO characteristics of our transflective LC cells within the extended 2×2 Jones matrix formalism [11]. The material parameters used for numerical simulations were the elastic constants, $K_1 = 11.6 \times 10^{-12}\,N$, $K_2 = 5.5 \times 10^{-12}\,N$, $K_3 = 16.1 \times 10^{-12}\,N$, 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. The effects of the twist angle and the cell gap on the EO characteristics were reported previously [12]. Based on the numerical results, the cell gap of 1.8 μm and the twist angle of 60° were selected to obtain the optimized EO characteristics.

RESULTS AND DISCUSSION

Figure 4 shows the experimental EO results and numerical simulations for the 60°-TN transflective cell as a function of the applied voltage. 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 Figure 4, it is clear that the EO characteristics of the transmissive and the reflective parts were very similar to each other. This similarity comes from the polarization guiding effect of the LTN layer with the twist of 60°. In our proposed transflective LCD, the optical path of the input light in the reflective part is twice larger than that in the transmissive part. This is not possible if the optical retardation effect of the LC layer is involved. In our case, a single driving scheme can be employed to operate the device. The

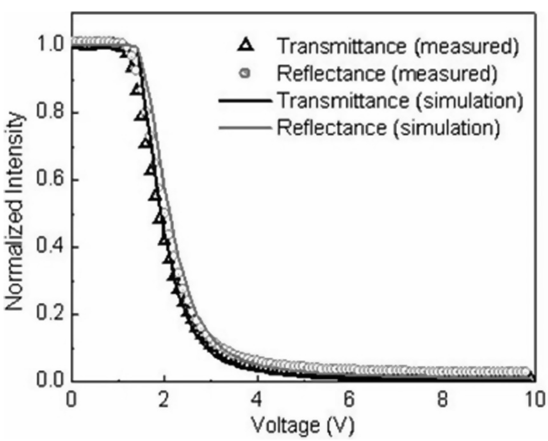


FIGURE 4 The EO characteristics of our transflective LTN cell. Open symbols and lines represent the experimental results and numerical simulations, respectively.

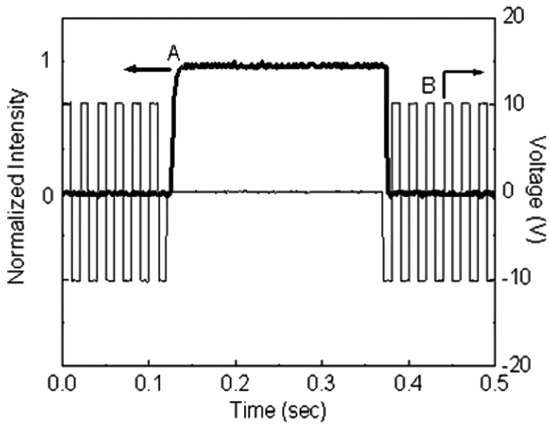


FIGURE 5 The EO response times of our transflective LC cell. The lines A and B are the normalized EO response and the pulse input, respectively.

measured EO response times are shown in Figure 5. The rising and falling times were found to be 5.8 msec and 0.8 msec, respectively. The switching times are fast enough for video-rate applications.

CONCLUSIONS

We demonstrated a new design of a transflective LCD having a single cell gap and a single LC mode. The retardation layer was fabricated by photo-patterning. The EO characteristics of the transmissive and the reflective parts were found to be quite similar, and thus a single driving scheme can be used. Due to the small cell gap, fast response times were obtained. The new design of our transflective LCD and the fabrication method of the patterned retardation layer are useful for mobile LCD applications.

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