# Fabrication of Multimode Transflective Liquid Crystal Display using the Photoalignment Technique with a Self-Masking Process

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## Abstract

*We report on a simple method of fabricating multimode transflective liquid crystal displays (LCDs) using the photoalignment technique. Using a self-masking process of ultraviolet light by the reflector as a photomask as well as a reflective mirror, the periodic multimode is obtained with no additional fabrication processes. Moreover, variations of the cell gap are not required for such trasflective LCDs*

## 1. Introduction

With increasing the demands for mobile devices, transflective liquid crystal displays (LCDs) have been extensively studied due to their superior performances in both indoor and outdoor environments. In general, the transflective LCD consists of two subpixels of the transmissive and reflective regions. In early studies, the cell gaps in the both transmissive and reflective subpixels were different from each other [1,2]. However, such transflective configurations with different cell gaps in the transmissive and reflective subpixels involve complex fabricating processes. The device performances, moreover, are degraded since the fringe-field effect and the LC deformation at a topographical boundary.

Recently, a few transflective LCDs, having the same cell gaps, with periodically patterned electrodes [3] and with two different modes in two subpixels [4] were proposed. In the transflective LCD structure with periodically patterned electrodes [3], the transmissive and reflective modes were achieved by an insulating reflector and the fringe-field effect produced by the periodically patterned electrodes. In this type, however, the optical performances of the transmissive and reflective parts are predetermined by the ratio of the transmissive area to the reflective area, which cannot be precisely controlled by the fringe field. The transflective LCD structure with two different modes, the vertically aligned mode and hybrid aligned mode, shows good optical performances such as high contrast ratio and achromaticity [4]. However, the assembling process of the multimode LC cell together with a slit-type reflector or an additional transflective film is required for the transflective LCD in a multimode configuration.

In this work, we propose a multimode transflective LCD using the photoalignment technique with a self-masking process. The multimode configuration consists of an electrically controllable birefringence (ECB) mode [5] in the transmissive region and a hybrid aligned nematic (HAN) mode [6] in the reflective region. The periodic multimodes in the transflective LCD were prepared using a single-step exposure of ultraviolet (UV) light on a photo-sensitive polymer layer. Since a metal reflector was used as a reflective mirror as well as an amplitude photomask, this multimode transflective LCD can be easily fabricated without any additional fabrication process such as masking or assembling process. Moreover, no additional component such as a slit-type reflector or an extra transflective film is required.

## 2. Operation Principle

Figure 1 shows the operation principles of our multimode transflective LCD consisting of the ECB mode for the transmissive part and the HAN mode for the reflective part. In the absence of an applied voltage, the LC molecules in the transmissive part were uniformly aligned parallel to the substrates due to the surface anchoring. When the phase retardation through the LC layer is $\lambda/2$, the linearly polarized light, passing through two quarter-wave (QW) plates and the homogeneously aligned LC layer with the phase retardation of half-wave, is rotated by 180° and thus optical transmission is produced as shown in Fig. 1(a). In the same situation, the phase retardation through the hybrid region is approximately $\lambda/4$. In the reflective part, the linearly polarized light passes through the QW plate and the hybrid aligned LC layer with the phase retardation of QW for incidence and reversely through the LC layer and the QW plate for reflectance. Therefore, the incident light experiences

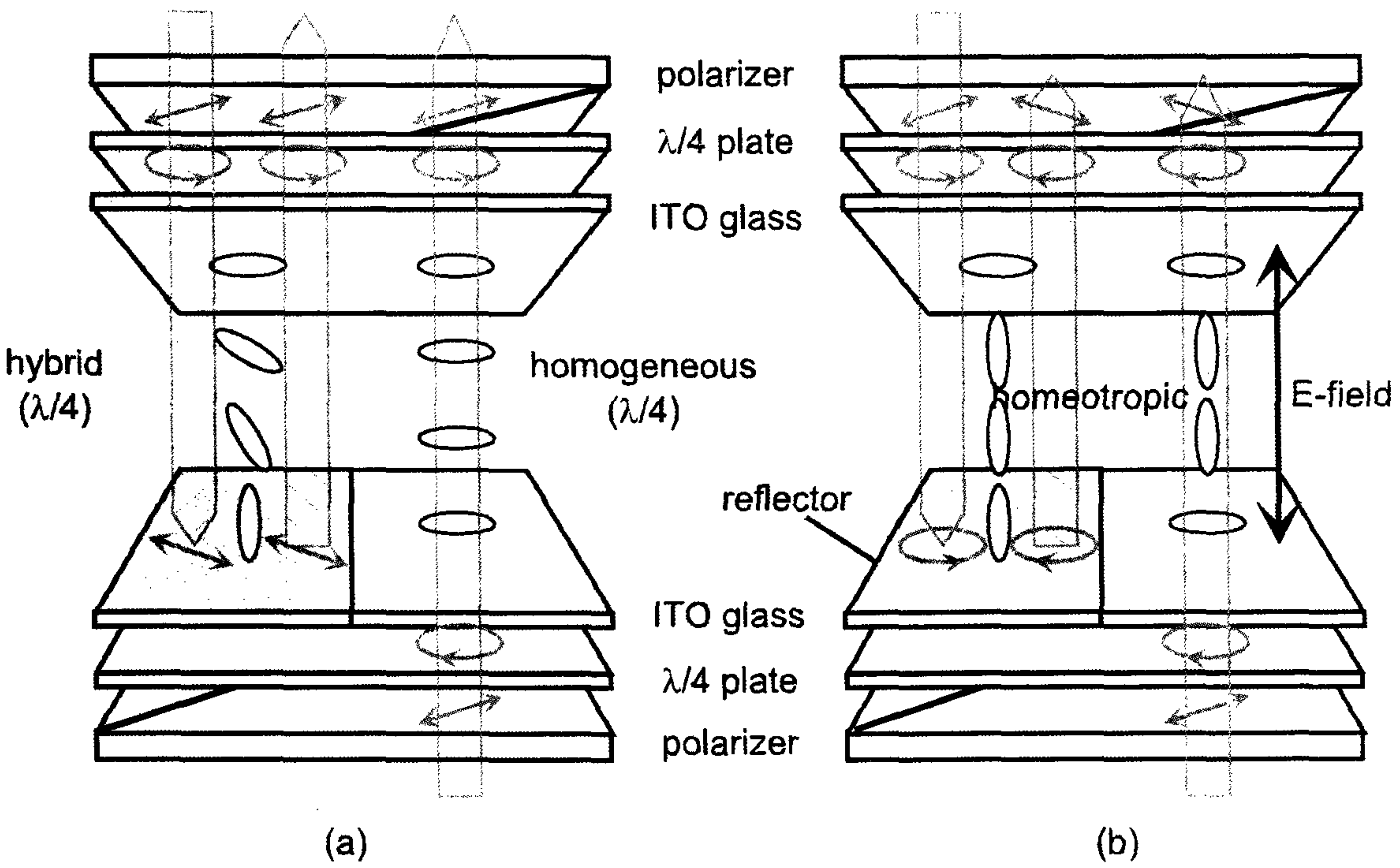


Figure 1. The operation principles of our multimode transflective LC cell consisting of the ECB mode for the transmissive part and the HAN mode for the reflective part: (a) the bright state in the absence of an applied electric field and (b) the dark state in the presence of an applied electric field.

twice of the phase retardation through the QW plate and hybrid LC layer of QW and thus optical reflection is achieved similar to the transmissive part.

When an electric field is applied, the LC molecules in both the homogeneous region and hybrid region, tend to align vertically for the LC with a positive dielectric anisotropy. In this deformed, vertically aligned LC configuration, no phase retardation occurs in both the transmissive and reflective regions. As shown in Fig. 1(b), in the transmissive region, the linearly polarized light, passing through two QW plates and the vertically aligned LC layer with no phase retardation, experiences the phase retardation of $\lambda/2$ and thus the polarization state of the incident light is rotated by 90°. Under parallel polarizers, the propagating light rotated by 90° with respect to the incident light is completely blocked. Similarly, in the reflective region where the LC molecules are vertically aligned, the incident light completely blocked by a single polarizer in the reflective part.

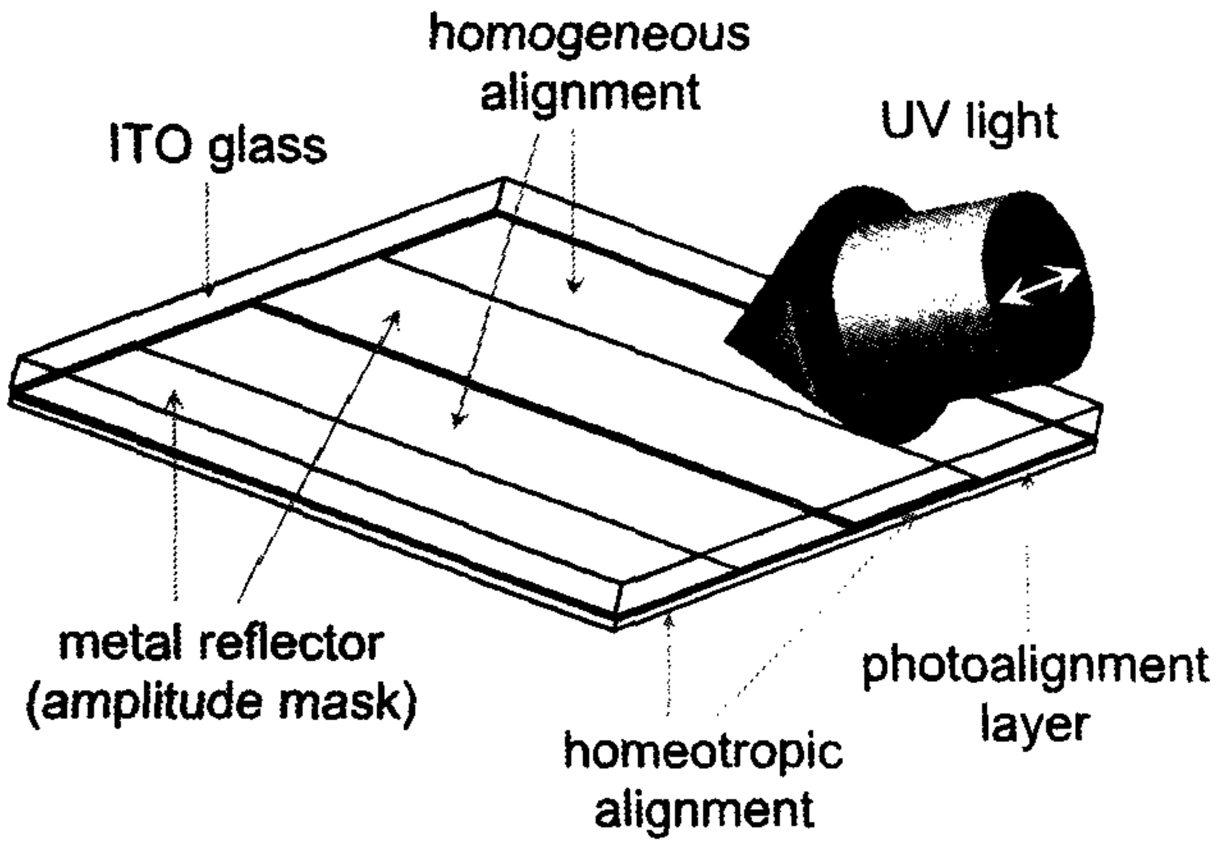


Figure 2. Fabrication process of the substrate with an alternating homogeneous and homeotropic geometry. The metal reflector is used as a mirror for the reflective part as well as an amplitude photomask.

## 3. Experiments

The multimode transflective LCD which consists of the periodically alternating homeotropic and hybrid geometry was fabricated using a single-step exposure of the UV light with no photomask on glass substrates coated with the photopolymer of LGC-M1 (LG Cable Ltd., Korea). The photopolymer aligns the LC

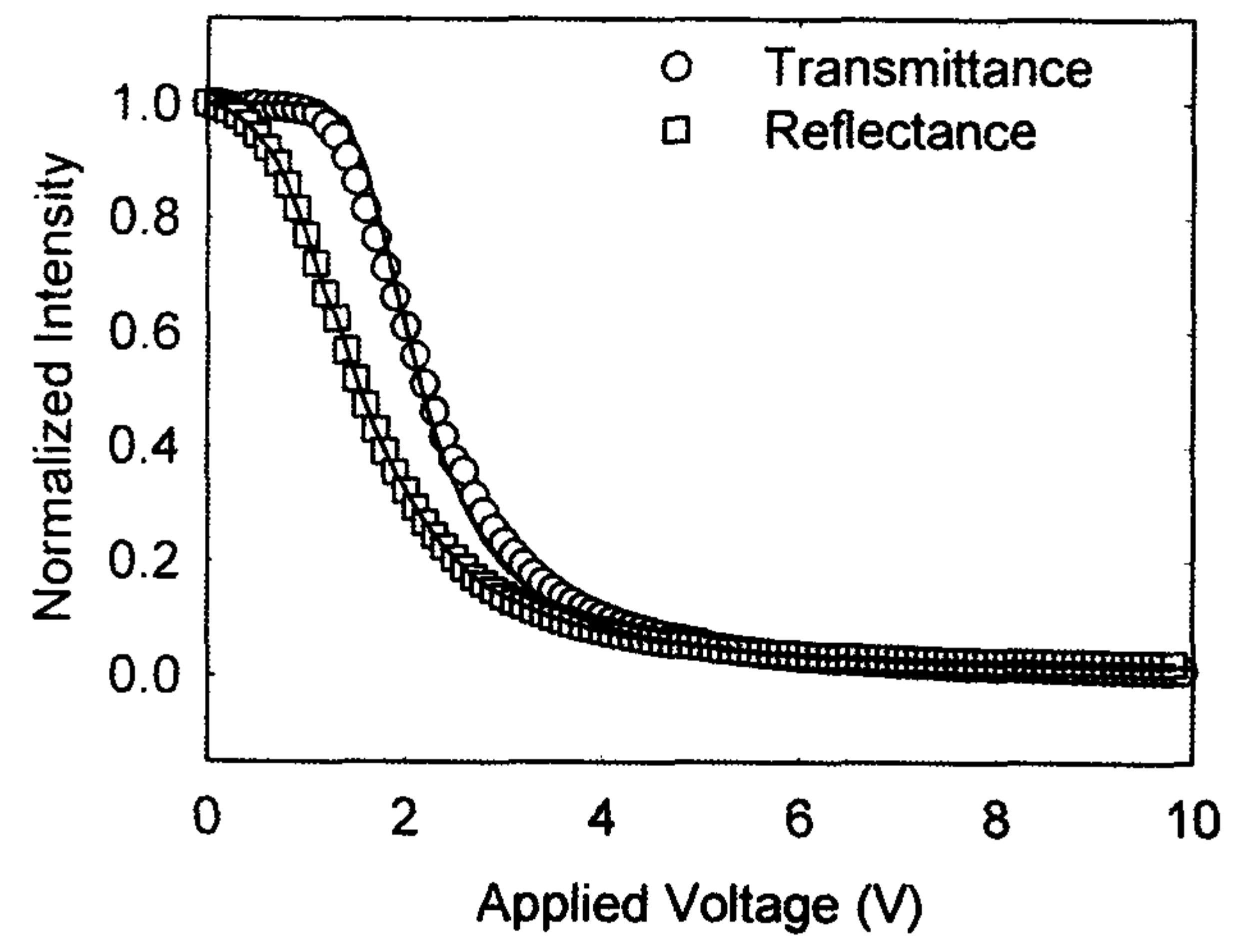


Figure 4. The EO characteristics of our transflective LC cell. The open symbols and the solid lines denote the experimental data and the simulation results, respectively.

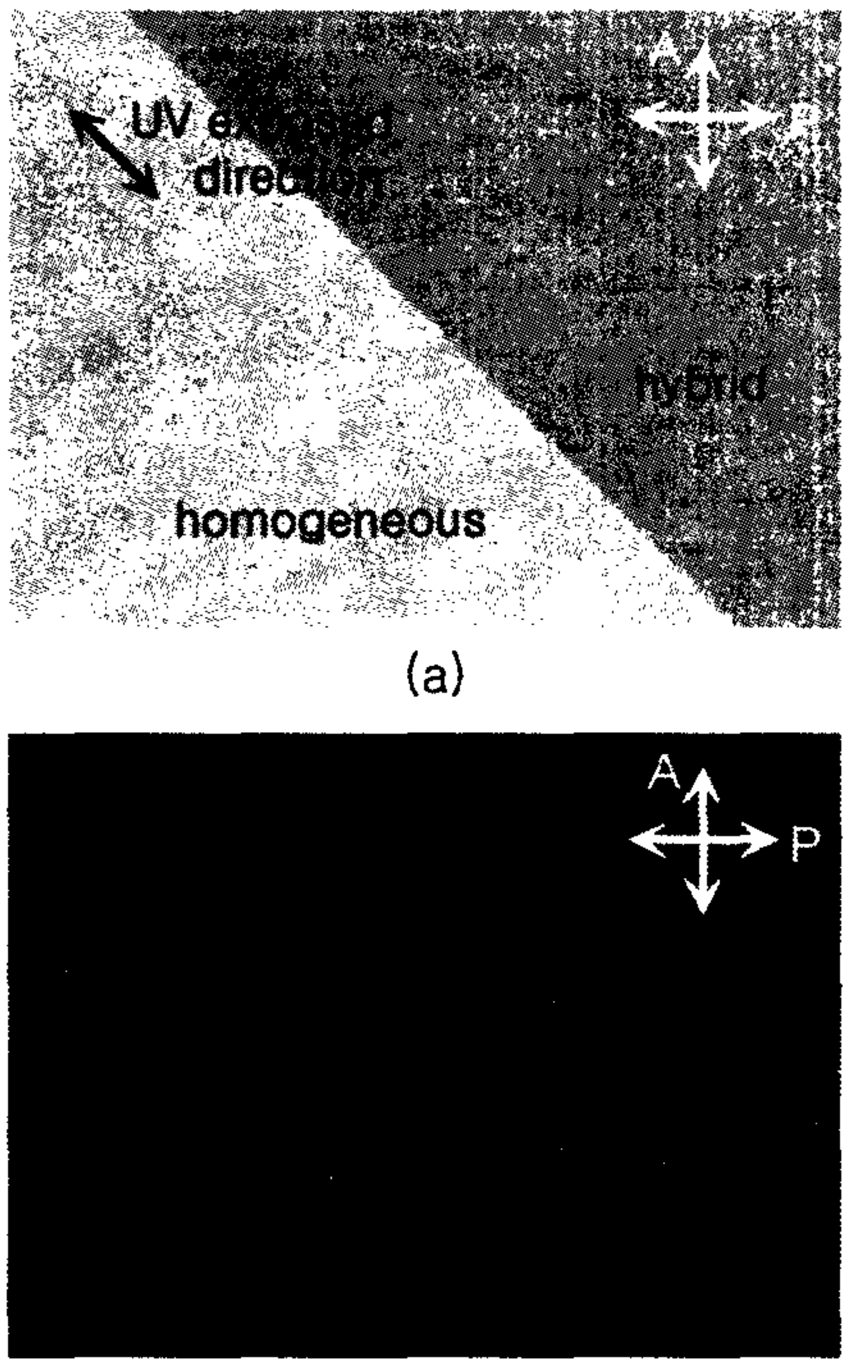
molecules homogeneously under the illumination of a linearly polarized UV light and homeotropically on a non-treated substrate with the UV light [7]. The chromium as a metal reflector is periodically deposited on the indium-tin-oxide (ITO) glass substrate with the periodicity of 150 μm. The photopolymer dissolved in cyclohexane was coated onto both the reflector-deposited ITO glass substrate and the bare ITO glass substrate, and baked at 150 °C for 30 min. The substrate having an alternating homeotropic and homogeneous geometry was prepared with a single-step exposure of the linearly polarized UV light from the reverse side of the reflector-deposited substrate as shown in Fig. 2. Here, the metal reflector was used as a mirror for the reflective mode as well as an amplitude photomask.

The nematic LC material used in this work was MLC-6012 of Merck. The ordinary and extraordinary refractive indices of MLC-6012 are $n_o$ = 1.4762 and $n_e$ = 1.5763 at wavelength of 632.8 nm, respectively. The dielectric anisotropy and the elastic constants are $\Delta\varepsilon$ = 8.2, $K_1 = 11.6\times10^{-12}$ N, $K_2 = 5.5\times10^{-12}$ N, and $K_3 = 16.1\times10^{-12}$ N, respectively [8]. The cell gap was maintained using glass spacers of 3.2 μm. A He-Ne laser of 632.8 nm and a polarizing microscope (Nikon, Optiphotpol II) were used for measuring the electro-optical (EO) properties and for observing the microscopic textures of the multimode transflective LC cell.

## 4. Results and Discussion

Figure 3 shows the microscopic textures of our multimode transflective LC cell observed under crossed polarizers. In order to *simultaneously* observe microscopic textures in the two regions using a polarizing microscope, the hybrid region was fabricated by the UV exposure through an amplitude photomask on the reverse side of the photopolymer coated ITO glass substrate. As shown in Fig. 3(a), in the absence of an applied voltage, the homogeneous region is brighter than the hybrid region due to the difference in the phase retardation in the two regions. In principle, the phase retardation in the homogeneous region is approximately twice as large as that in the hybrid region. Under an applied voltage of 10 V, as shown in Fig. 3(b), no light is transmitted through the LC cell and thus a complete extinction is achieved in the both the homogeneous and hybrid regions since the LC with a positive dielectric anisotropy is aligned perpendicular to the substrate.

The transmittance and reflectance in our multimode transflective LC cell are shown as a function of the applied voltage in Fig. 4. Here, the



(a)

(b)

Figure 3. Microscopic textures of our multimode transflective LC cell observed under crossed polarizers at an angle of 45° between the UV exposed direction and one of the crossed polarizers for the applied voltages of (a) 0 V and (b) 10 V.

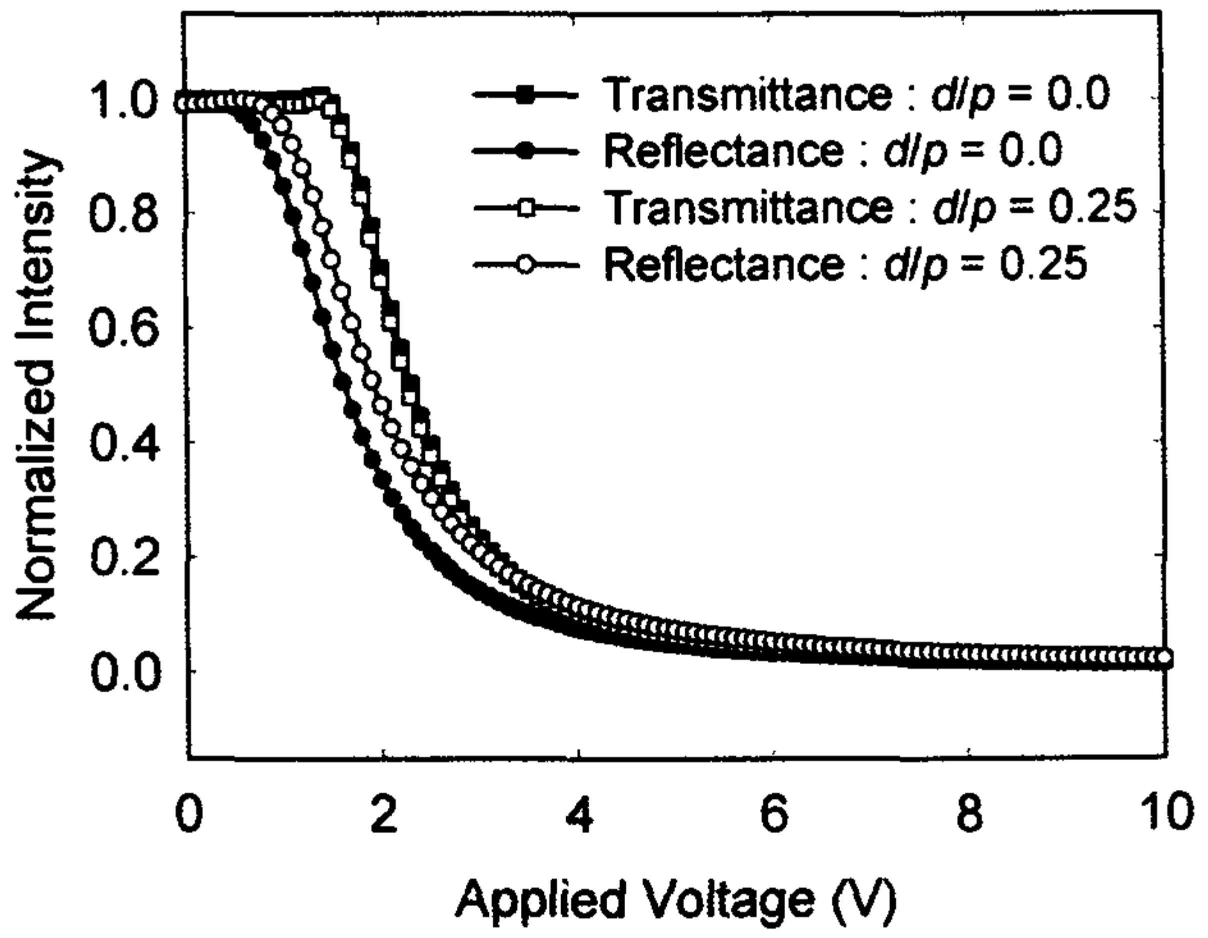


Figure 5. The numerical simulations of the EO characteristics of our transflective LC cell for a different $d/p$.

open circles and rectangles denote the experimental results in the transmissive (homogeneous) and reflective (hybrid) regions, respectively. The solid lines represent the simulation results obtained by the relaxation method [9] within the elastic continuum theory [10]. It is noted that the Frederiks transition [10] was observed in homogeneously aligned region and no threshold voltage was shown in the hybrid region.

In our multimode transflective LCD, however, the EO characteristics for the transmissive and reflective modes are different from each other. In order to reduce the difference of the EO properties between two modes, we introduced the ratio $d/p$ of the cell gap $d$ to helical pitch $p$ produced by a chiral dopant in the numerical simulations. Fig. 5 shows the numerical results of the transmittance and the reflectance of the transflective LC cell. With increasing $d/p$ up to 0.25, the difference of the EO characteristics between two modes, the transmissive mode and the reflective mode, the transmissive region and the reflective regions, was significantly reduced.

## 5. Conclusion

In summary, we proposed a simple fabricating method of the transflective LCD in the multimode configuration, consisting of the ECB mode for a transmissive part and the HAN mode for a reflective part, with the same cell gap. The multimode structure was prepared using the photoalignment technique with a self-masking process of metal reflector. The photoploymer used in this work aligns the LC molecules homogeneously under the linearly polarized UV light and homeotropically with no UV treatment. The metal reflector was used as a reflective mirror as well as an amplitude photomask, producing an alternating homogeneous and homeotropic geometry. As a result, our multimode transflective LCD was easily fabricated without any additional fabrication process and an extra component. Since the reflective region depends on only the area of the metal reflector, the ratio of the reflective region to the transmissive region is fully adjustable by varying the aperture ratio of the metal reflector. Adding the chiral dopant to the LC, moreover, the difference of the EO properties between the transmissive mode and the reflective mode was significantly reduced. A practical way of combining the ECB mode and the HAN mode for transflective LCDs with fixed cell gap remains to be explored.

## 6. Acknowledgement

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