Multimode Configuration Doped with a Chiral Agent for Transflective Liquid Crystal Display with a Single Cell Gap

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Abstract

We demonstrate a transflective liquid crystal display (LCD), doped with a chiral agent to produce a low helical twisting power, in a multimode configuration consisting of the homogeneous alignment and the hybrid alignment. The multimode transflective LCD with a single cell gap was fabricated using a single-step photoalignment technique with a self-masking process of an array of metal reflectors in the reflective region. In our configuration, the electro-optical disparity between the transmissive region and the reflective region was found to be significantly reduced by the low helical twisting power of the chiral dopant.

Keywords : transflective LCD, multimode, photoalignment, chiral dopant

1. Introduction

With increasing the demands for mobile devices, reflective liquid crystal displays (LCDs) have been extensively studied because of lightweight and low power consumption. In dark or dimly lit areas, however, the reflective LCDs do not have good image quality because no backlight is utilized. Recently, transflective liquid crystal displays have attracted much interest for mobile applications since their superior device performances can be obtained under both indoor and outdoor environments. Generally, a transflective LCD consists of two subpixels of the transmissive and reflective parts. In early transflective LCDs, the cell gaps in the both transmissive and reflective subpixels were different from each other [1, 2]. In such transflective configuration, however, the complex processes of fabricating two different cell gaps in the transmissive and reflective subpixels are inevitably involved and the device performances are degraded due to the fringe-field effect and the LC deformation at topographical boundaries.

Recently, various transflective LCDs with a single cell gap, having periodically patterned electrodes [3~5] or two different modes in two subpixels [6~8], were proposed. In the transflective LCD patterned periodically, the transmissive and reflective display modes were realized using an insulating reflector and the fringe-field effect produced by the periodically patterned electrodes. In such transflective LCD, 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 having two different, vertically aligned and hybrid aligned modes was found to show high contrast ratio, wide viewing characteristics, and achromaticity [6]. Another multimode configuration with the uniformly aligned and hybrid aligned modes was fabricated using the ultraviolet (UV) exposure [7, 8]. However, the above existing multimode transflective LCDs require a slit-type reflector or an additional transflective film [6, 8]. Moreover, the electro-optical (EO) disparity between the transmissive and reflective subpixels limits the image quality and causes complexity in driving circuits.

In this work, we demonstrate a multimode transflective LCD, doped with a chiral agent to produce a low helical twisting power, with single cell gap using a self-masking process of the photoalignment technique. The multimode configuration consists of the homogeneous alignment in the transmissive region and the hybrid alignment in the reflective region. Our periodic multimodes

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in the transflective LCD were prepared using a single-step exposure of UV light on a photo-sensitive polymer layer, aligning the LC molecules homogeneously under a linearly polarized ultraviolet (LPUV) light and homeotropically under no UV light [9]. Since an array of metal reflectors in the reflective region is used as an amplitude photomask producing an alternating homogeneous and homeotropic geometry, the multimode transflective LCD can be easily fabricated with no additional process and component [7]. A small amount of a chiral dopant was introduced into the LC to produce a helicoidal structure with a long helical pitch. In our previous study [10], the appearance of the helical structure was essential to significantly reduce the EO disparity between the transmissive and reflective regions.

2. Operating Principles

Fig. 1 shows the operation principles of our transflective LC cell with a single cell gap in a multimode configuration. In this multimode transflective LC cell, the LC molecules are homogeneously aligned in the transmissive region and hybrid aligned in the reflective region when no chiral dopant is introduced [7]. In the absence of an applied voltage, the LC molecules in the transmissive region were uniformly aligned parallel to the substrates due to the surface anchoring. In the reflective region, the LC molecules were hybrid aligned and the phase retardation of the light passing through the reflective region twice is equivalent to that through the transmissive region [7]. If the phase retardation through the LC layer in the homogeneously aligned (transmissive) region is $\lambda/2$, the phase retardation in the hybrid aligned (reflective) region is approximately $\lambda/4$, where λ denotes the wavelength of the incident light. In such case, the polarization state of a linearly polarized light, passing through two quarter-wave (QW) plates and the homogeneously aligned LC layer with the phase retardation of $\lambda/2$, is rotated by 180°, and thus optical transmission is produced in the transmissive region as shown in Fig. 1(a). In the reflective part, the linearly polarized light passes through one QW plate and the hybrid aligned LC layer with the phase retardation of $\lambda/4$ for incidence and reversely through the LC layer and the QW plate for reflectance. Therefore, the incident light experiences twice of the phase retardation of both the QW plate and hybrid LC layer of $\lambda/4$, and thus optical reflection
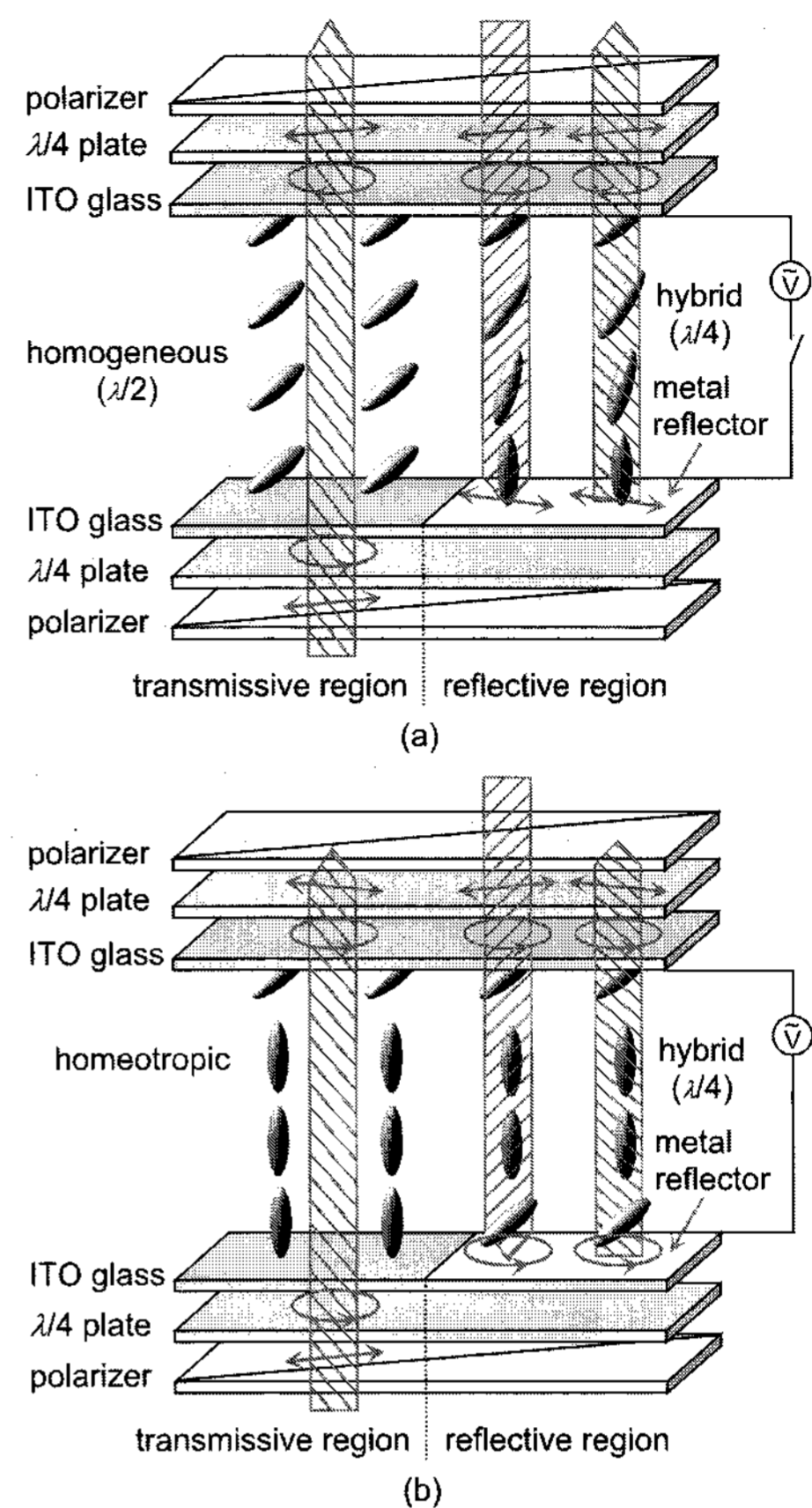
Fig. 1. The operating principles of our transflective LC cell with a single cell gap in a multimode configuration consisting of the ECB mode for the transmissive region and the HAN mode for the reflective region: (a) the bright state in the absence of an applied electric field and (b) the dark state in the presence of an applied electric field.

is achieved similar to the transmissive part.

When an external voltage is applied, in the two regions, the homogeneous region and the hybrid region, the LC with a positive dielectric anisotropy becomes to align vertically. In the vertically aligned 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 polarization state of propagating light rotated by 90° with respect to that of the incident light is completely blocked. Similarly, in the reflective region where the LC molecules are also vertically aligned, the incident light completely blocked by a single

polarizer in the reflective part.

In the aforementioned configuration of the multimode transflective LCD, the phase retardation of the light passing through the reflective region twice is equivalent to that through the transmissive region in the bright and dark states [7]. In the intermediate states, however, the EO properties of the two subpixels differ from each other due to the difference in the threshold behavior [11] between the electrical controllable birefringence (ECB) mode [12] and the hybrid aligned nematic (HAN) mode [13].

When a chiral dopant is introduced into the LC, the LC director profiles are influenced by the helical twisting power. In the transmissive region, the LC molecules are homogeneously aligned irrespective of the helical twisting power due to the planar surface anchoring energy at both substrates. In the reflective region, however, the LC director is slightly twisted by the chiral dopant since the azimuthal anchoring is negligibly small on the homeotropic alignment layer. In the reflective LC cell in the twisted hybrid (TH) geometry [14], it was found that the phase retardation through the LC layer decreases slowly with increasing the applied voltage in the low voltage regime because of the helical twisting power. As a consequence, the EO disparity between the transmittance and the reflectance is significantly reduced in this configuration.

3. Experiments

The multimode transflective LCD, consisting of the periodically alternating homeotropic and hybrid geometry, was fabricated using a self-masking process of the photoalignment technique on glass substrates coated with the photopolymer of LGC-M1 (LG Cable Ltd., Korea). The photopolymer aligns the LC molecules homogeneously under the illumination of an LPUV light and homeotropically on a non-treated substrate with the UV light [9]. An array of chromium reflectors with the periodicity of 150 μm was prepared on the indium-tin-oxide (ITO) glass substrate. After the photopolymer dissolved in cyclohexane was coated onto the ITO glass substrates, the two substrates were baked at 150°C for 30 min. One of the baked substrates was exposed to the LPUV light in the whole area to produce uniformly homogeneous alignment. The other having the alternating homeotropic and homogeneous LC alignment was prepared using a self-
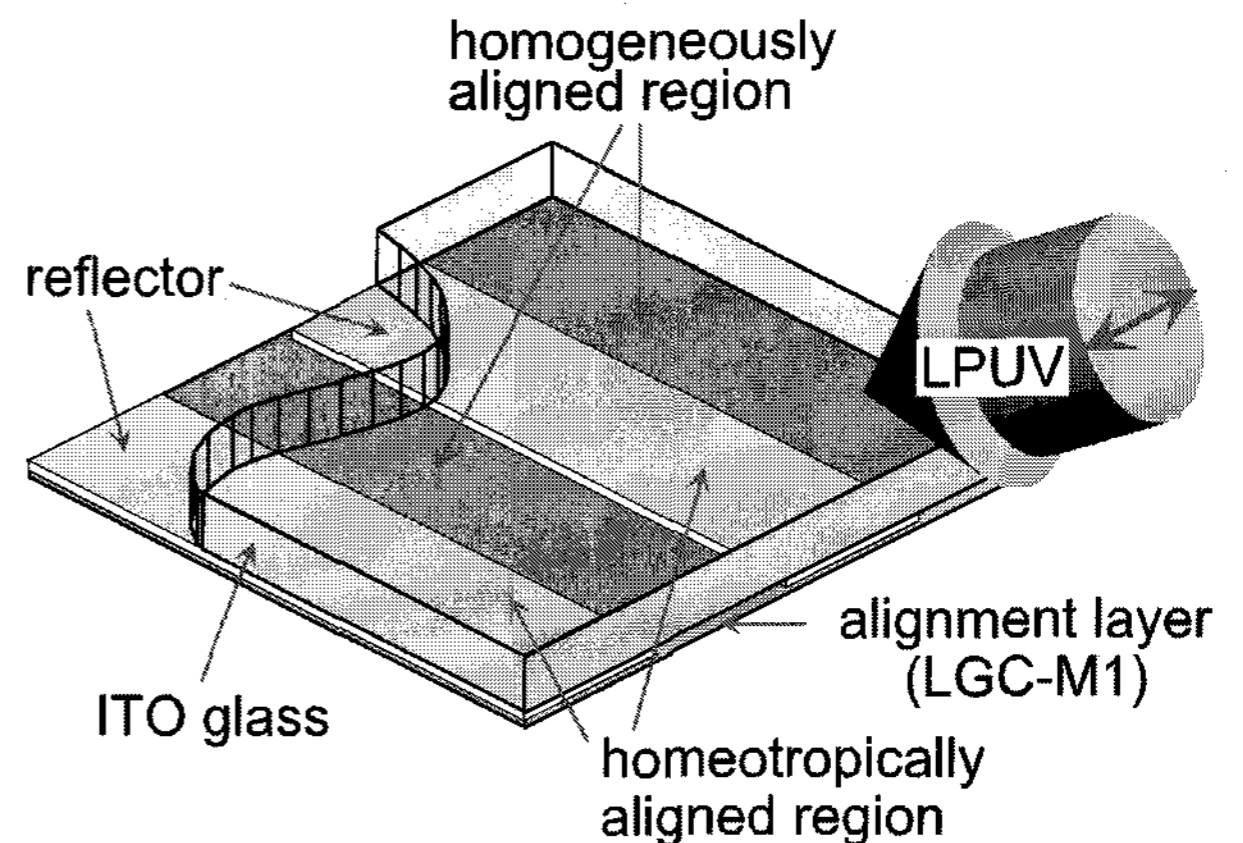

Fig. 2. The self-masking process of photoalignment for producing the periodically homogeneous and homeotropic alignments. The photoalignment layer of LGC-M1 aligns the LC molecules homogeneously under the LPUV exposure and homeotropicaly under no UV treatment. An array of metal reflectors was used as an array of mirrors for the reflective part as well as an amplitude photomask for producing the multi-alignment.

masking process of photoalignment technique [10]. As shown in Fig. 2, the LPUV light incident from the outside of the substrate was blocked by the metal reflectors. Note that the metal reflectors were served as the mirrors for the reflective parts as well as an amplitude photomask for the periodic LC alignment. The reflective area relative to the transmissive area depends solely on the aperture ratio of the metal reflector.

The nematic LC material used in this work was MLC-6012 of E. 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 [15]. The chiral dopant of S-811 was introduced into the LC to produce a helical structure. The doping concentration was adjusted to give $d/p = 0.25$, where d and p denote the cell gap and the natural pitch of the helicoidal structure, respectively. The cell gap was maintained using glass spacers of 3.2 μm. A He-Ne laser of 632.8 nm was used as a light source and a polarizing optical microscope (Nikon, Optiphotpol II) was used for observing microscopic textures of the multimode trans-flective LC cell. All the measurements were carried out at room temperature.

4. Results and Discussion

Fig. 3 shows microscopic textures of our multimode transflective LC cell observed in the bright and dark states under crossed polarizers. Here, no reflector was prepared in the hybrid region to show purposely the boundary between the homogeneous and hybrid regions. In this case, no chiral dopant was used to distinguish between the two regions. As shown in Fig. 3(a), in the absence of an applied voltage, the homogeneous region is somewhat brighter than the hybrid region due to the difference in the phase retardation between the two regions. As discussed above, the phase retardation in the homogeneous region is approximately two times lager than that in the hybrid region. Under the applied voltage of 10 V, as shown in Fig. 3(b), no light was transmitted through the LC cell and thus a complete
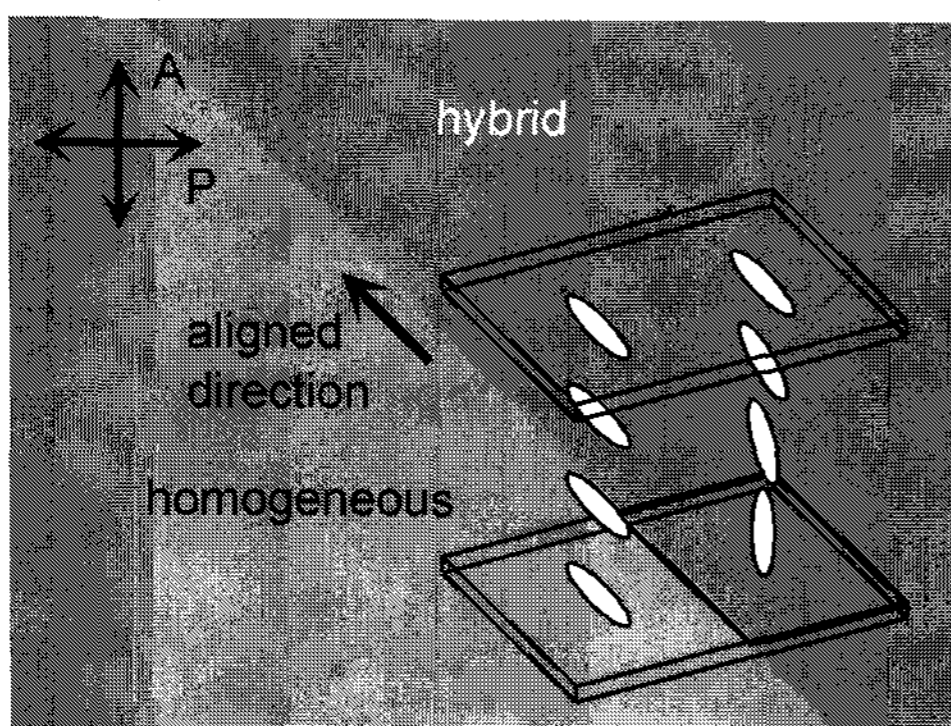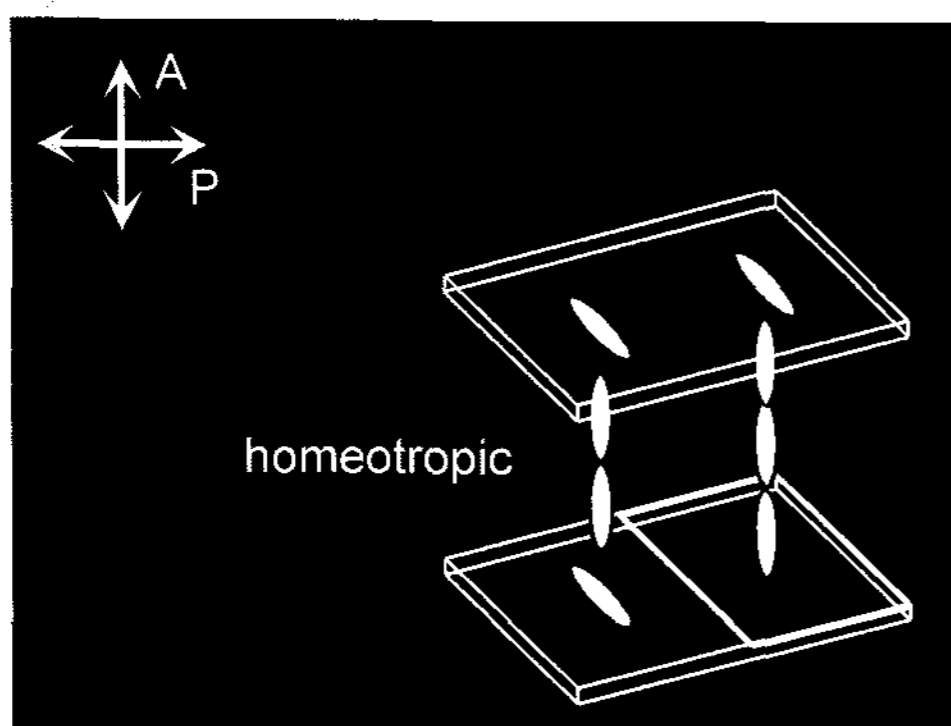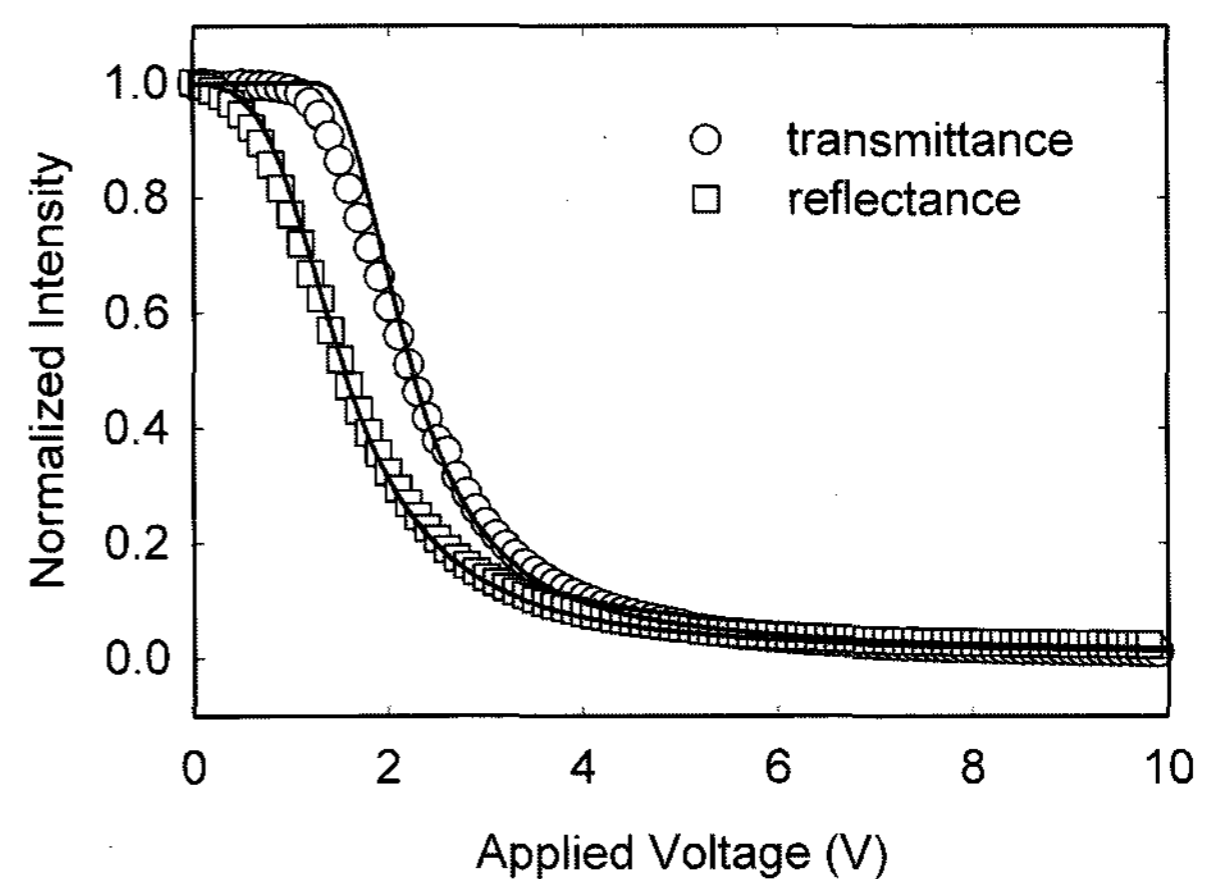
extinction was achieved in both the homogeneous and hybrid regions since the LC with a positive dielectric anisotropy is aligned perpendicular to the substrate.

The transmittance and reflectance in our multimode transflective LC cell are shown in Fig. 4 as a function of the applied voltage. Here, the open circles and rectangles denote the experimental data of the transmittance and those of the reflectance, respectively. The solid lines represent the simulation results obtained by the relaxation method [16] in the elastic continuum theory [11]. It is noted that the Frederiks transition [11] was observed in the homogeneously aligned region while no transition was present in the hybrid region. It is clear that the EO disparity between the transmissive and reflective regions is different from each other.
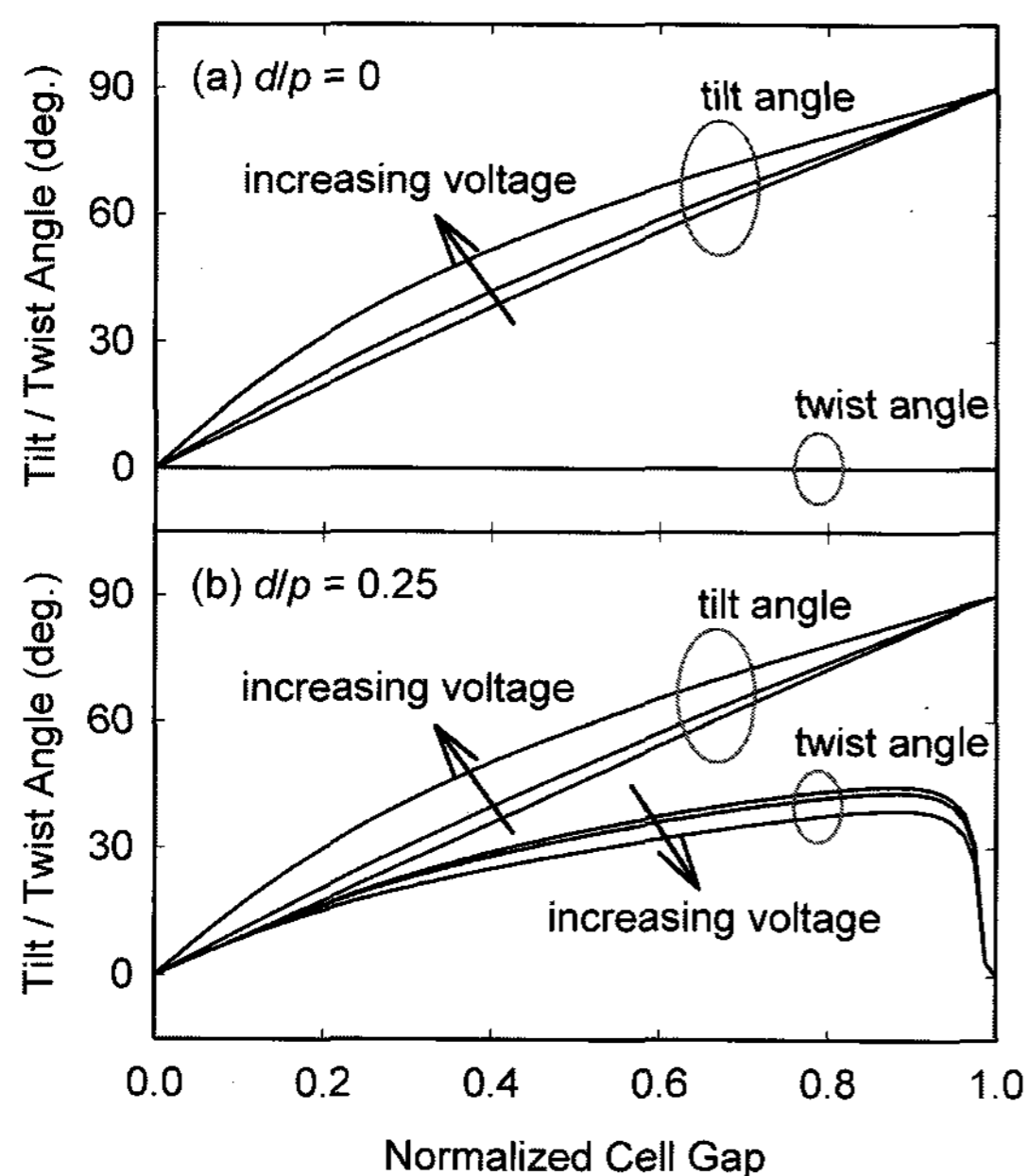
When a chiral dopant is introduced into the LC, the distortion energy of the LC is influenced by the helical twisting power, and thus the LC director profiles are somewhat perturbed. There is no change in the tilt angle distribution irrespective of the helical twisting power in both the homogeneous and hybrid regions since the tilt angle of the LC director depends mainly on the external field. In the twist angle distribution, however, significant variations arise from the helical twisting power produced by the chiral dopant. In general, the large deformation of the twist angle is generated near a vertically oriented region where the elastic deformation of the LC medium is minimized.

(a)

(b)

Fig. 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. Here, no reflector was prepared in the hybrid region to purposely show the boundary between the two regions.

Fig. 4. The EO characteristics of our multimode transflective LC cell for $d/p = 0$. The open circles and the open rectangles denote the experimental data of the transmittance and those of the reflectance, respectively. Here, the solid lines represent the numerical simulations of the transmittance and the reflectance in the elastic continuum theory.

Below the Frederiks threshold [11], the LC molecules in the transmissive region are homogeneously aligned irrespective of the helical twisting power due to the planar surface anchoring energy at both substrates. With increasing the applied field, the LC directors were oriented vertically and twisted in the middle layer. However, the variation of the phase retardation induced by the twist angle of the LC is negligible in the vertically oriented region. As a result, in the transmissive region, there is no change in the EO property in the presence of the helical twisting power.
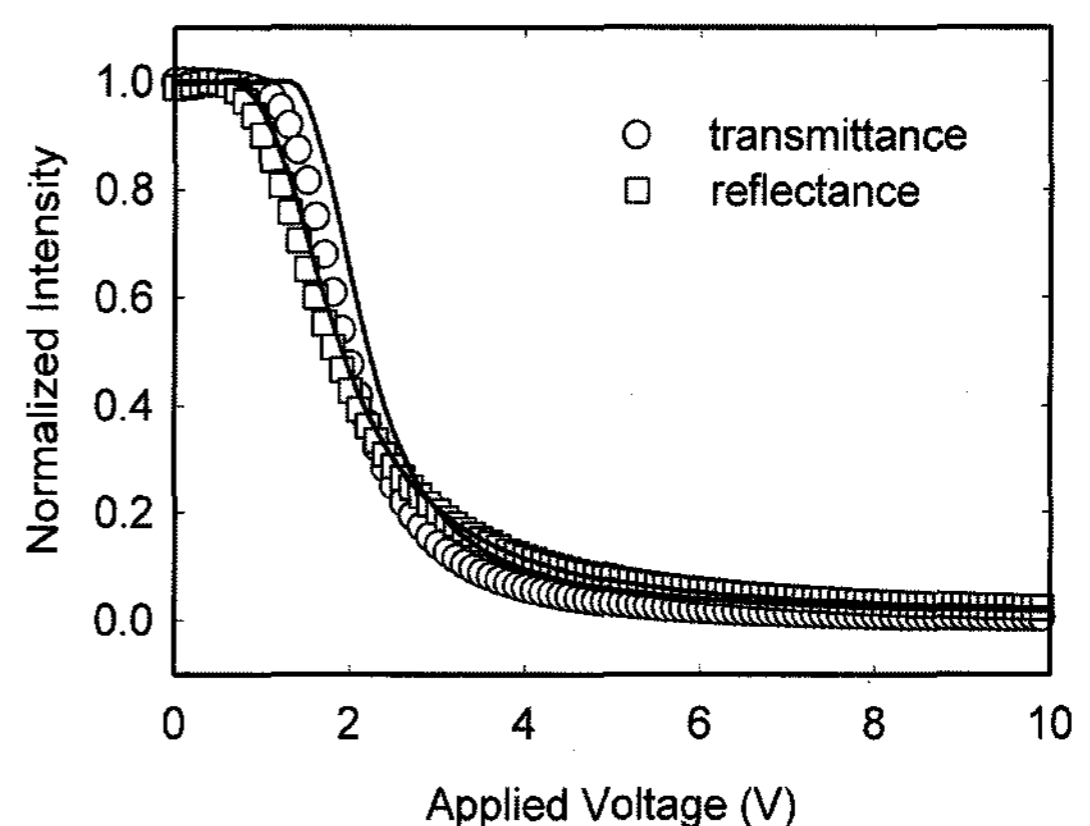
In the reflective region, however, the deformation of the twist angle is produces near the homeotropic region even in the absence of an applied electric field. Figs. 5(a) and (b) show the LC director profiles, calculated in the elastic continuum theory [11], in the reflective region at various applied voltages. As discussed above, the disparity in the tilt angle profiles between two cases, $d/p = 0$ and $d/p = 0.25$, is negligible. However, the twist angle profiles differ from each other as shown in Fig. 5. In the reflective LC cell with no chiral dopant, the tilt angle remains unchanged with increasing the applied voltage. The twist angle is slightly rotated by the chiral dopant since the azimuthal anchoring energy is negligibly small on the homeotropic alignment layer as shown in Fig. 5(b). In the reflec-

reflective LC cell in the twisted hybrid (TH) geometry [14], it was found that the phase retardation through the LC layer decreases slowly with increasing the applied voltage in the low voltage regime because of the helical twisting power. As a consequence, the reflectance shows a quasi-threshold behavior and the EO disparity between the transmittance and the reflectance is significantly reduced in this configuration.

Fig. 6 shows the EO characteristics of our multimode transflective LC cell doped with a chiral agent to give $d/p = 0.25$. Here, the open circles and rectangles denote the experimental data of the transmittance and those of the reflectance, respectively. The solid lines represent the simulation results in the presence of the helical twisting power. As shown in Figs. 4 and 6, there is no appreciable difference in the transmittance between $d/p = 0$ and $d/p = 0.25$. However, the reflectance differs from that shown in Fig. 4. Moreover, it shows a quasi-threshold behavior similar to the transmittance. In fact, above $d/p = 0.25$, a π-twisted configuration is energetically more stable than a uniformly aligned configuration [17]. For $d/p = 0.25$, the reflectance curve coincides well with the transmittance curve due to the presence of the helical twisting power in the TH region as shown in Fig. 6. Clearly, the EO disparity between the transmissive and the reflective regions is significantly reduced by introducing a chiral dopant into the LC.

Fig. 5. The LC director profiles in the hybrid aligned region for (a) $d/p = 0$ and (b) $d/p = 0.25$ at the applied voltages of 0 V, 0.5, and 1.0 V. Here, the tilt angle and the twist angle were obtained in the elastic continuum theory.

Fig. 6. The EO characteristics of our multimode transflective LC cell for $d/p = 0.25$. The open circles and the open rectangles denote the experimental data of the transmittance and those of the reflectance, respectively. Here, the solid lines represent the numerical simulations of the transmittance and the reflectance in the elastic continuum theory.

5. Conclusions

We demonstrated a transflective LCD with a single cell gap in the multimode configuration consisting of the ECB mode for the transmissive part and the HAN mode for the reflective part. The multimode transflective LC structure was prepared using a single-step photoalignment technique with a self-masking process of an array of metal reflectors in the reflective region. In our transflective LCD, the reflective area relative to the transmissive area was precisely controlled by simply varying the aperture ratio of the metal reflector. Moreover, the EO disparity between the transmissive and reflective regions was significantly reduced by the helical twisting power induced by the chiral dopant in the reflective HAN region.

References

[1] H.-I. Baek, Y.-B. Kim, K.-S. Ha, D.-G. Kim, and S.-B. Kwon, in *IDW'00* (2000), p. 41.

[2] M. Jisaki and H. Yamaguchi, in *IDW'01* (2001), p. 133.

[3] T. B. Jung, J. C. Kim, and S. H. Lee, *Jpn. J. Appl. Phys.* **42**, L464 (2003).

[4] S. H. Lee, H. W. Do, G.-D. Lee, T.-H. Yoon, and J. C. Kim, *Jpn. J. Appl. Phys.* **42**, L1455 (2003).

[5] J. H. Song and S. H. Lee, *Jpn. J. Appl. Phys.* **43**, L1130 (2004).

[6] S. H. Lee, K.-H. Park, J. S. Gwag, T.-H. Yoon, and J. C. Kim, *Jpn. J. Appl. Phys.* **42**, 5127 (2003).

[7] C.-J. Yu, J. Kim, D.-W. Kim, and S.-D. Lee, in *SID'04 Digest* (2004), p. 642.

[8] Y. Y. Fan, H. C. Chiang, T. Y. Ho, Y. M. Chen, Y. C. Hung, I. J. Lin, C. R. Sheu, C. W. Wu, D. J. Chen, J. Y. Wang, B. C. Chang, Y. J. Wong, and K. H. Liu, in *SID'04 Digest* (2004), p. 647.

[9] J.-H. Park, C.-J. Yu, J. Kim, S.-Y. Chung, and S.-D. Lee, *Appl. Phys. Lett.* **83**, 1918 (2003).

[10] C.-J. Yu, J. Kim, D.-W. Kim, and S.-D. Lee, in *IMID'04* (2004), p. 834.

[11] P. G. de Gennes and J. Prost, *The Physics of Liquid Crystals*, 3rd ed. (Oxford University Press, New York, 1993).

[12] G. H. Heilmeier, J. A. Castellano, and L. A. Zanoni, *Mol. Cryst. Liq. Cryst.* **8**, 293 (1969).

[13] S. Matsumoto, M. Kawamoto, and K. Mizunoya, *J. Appl. Phys.* **47**, 3842 (1976).

[14] Y. J. Kim and S.-D. Lee, *Appl. Phys. Lett.* **72**, 1978 (1998).

[15] Data provided by E. Merck.

[16] W. H. Press, B. P. Flannery, S. A. Teukolsky, and W. T. Vetterling, *Numerical Recipes : The Art of Scientific Computing*, (Cambridge University Press, New York, 1986).

[17] C.-J. Yu, Y. J. Jeon, S. Hong, and S.-D. Lee, *Jpn. J. Appl. Phys.* **43**, 5435 (2004).