Multimode transflective liquid crystal display with a single cell gap using a self-masking process of photoalignment

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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 was fabricated by a single-step exposure of the UV light through an array of metal reflectors used as an amplitude photomask which gives an alternating homogeneous and homeotropic LC geometry. This single-step UV exposure produces no cell gap variations. 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.

Transflective liquid crystal displays (LCDs) have been extensively studied for mobile applications since their superior device performances can be achieved under both indoor and outdoor environments. Basically, a transflective LCD consists of two subpixels of the transmissive and reflective regions. In early transflective LCDs, the cell gaps in the two subpixels are generally different from each other. However, such transflective configurations with different cell gaps in the transmissive and reflective subpixels require complex fabrication processes. Moreover, the disparity of the electro-optical (EO) performances in the two subpixels is inevitably involved because of the fringe-field effect and the LC deformations at topographical boundaries produced from the different cell gaps.

Recently, various transflective LCDs with a single cell gap, having periodically patterned electrodes or two different modes in two subpixels, were proposed. In the periodically patterned transflective LCD having an insulating reflector, the EO effects in the transmissive and reflective subpixels are predetermined by the ratio of the transmissive area to the reflective area. In this case, the different optical characteristics should be precisely balanced by the fringe field. A transflective LCD having two different, vertically aligned and hybrid aligned modes showed high contrast ratio, wide viewing characteristics, and achromaticity. Another multimode configuration with the uniformly aligned and hybrid aligned modes was fabricated using the Ar+ ion-beam exposure or the UV exposure. However, the above existing multimode transflective LCDs require a slit-type reflector or an additional transflective film. Moreover, the EO disparity between the transmissive and reflective subpixels limits the image quality and causes complexity in driving circuits.

In this work, we demonstrate a type of multimode transflective LCD with a single cell gap. The transflective LCD has the homogeneous alignment in the transmissive region and the hybrid alignment in the reflective region. Two different modes arranged periodically in the transflective LCD were produced using a single-step exposure of the UV light on a photosensitive polymer layer which aligns the LC homogeneously under a linearly polarized ultraviolet (LPUV) light and homeotropically under no UV light. In such multimode configuration, an array of metal reflectors was used as an amplitude photomask, which produces an alternating homogeneous and homeotropic geometry. A small amount of a chiral dopant was introduced into the LC to produce a helicoidal structure with a long helical pitch. As will be discussed later, the appearance of the helical structure is essential to significantly reduce the EO disparity between the transmissive and reflective regions.

Figure 1 shows a schematic diagram 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. If a 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 \( \lambda \) denotes the wavelength of the incident light. In both the bright and dark states, the phase

FIG. 1. The schematic diagram of our transflective LC cell with a single cell gap in a multimode configuration consisting of the homogeneous alignment in the transmissive region and the hybrid alignment in the reflective region in the absence of a chiral dopant.
retardation on passing through the reflective region twice is then equivalent to that through the transmissive region. In the intermediate states, the EO properties of the two subpixels differ from each other due to the difference in the threshold behavior between the electrical controllable birefringence mode and the hybrid aligned nematic mode.

Due to the chiral dopant 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. In the reflective region, however, the LC director is slightly twisted with respect to the surface normal since the azimuthal anchoring energy is negligible on the homeotropic alignment layer. In the reflective LC cell in the twisted hybrid (TH) geometry, 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. This is one of the most important features of our multimode transflective LC cell in contrast to the homogeneously aligned cell showing the distinct threshold behavior.

The multimode transflective LC cell in a periodically alternating homeotropic and hybrid geometry was fabricated using a single-step exposure of the UV light on glass substrates coated with a photosensitive polymer of LGC-M1 (LG Cable Ltd., Korea). The photopolymer is capable of aligning the LC molecules homogeneously under the illumination of the LPUV light and homeotropically under no UV light. An array of chromium reflectors with the periodicity of 150 µm was prepared on the indium-tin-oxide (ITO) glass substrate. After the photopolymer 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 UV light in the whole area to produce uniformly homogeneous alignment. The other having an alternating homeotropic and homogeneous LC alignment was prepared using a self-masking process of photoinitiation. As shown in Fig. 2, the LPUV light illuminated from the outside of the substrate is blocked by the metal reflectors. Note that the array of metal reflectors was served as the array of mirrors for the reflective region as well as an amplitude photomask for periodic LC alignment. The reflective area relative to the transmissive region as well as an amplitude photomask for producing an alternating homogeneous and homeotropic geometry.

Due to the chiral dopant 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. In the reflective region, however, the LC director is slightly twisted with respect to the surface normal since the azimuthal anchoring energy is negligible on the homeotropic alignment layer. In the reflective LC cell in the twisted hybrid (TH) geometry, 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. This is one of the most important features of our multimode transflective LC cell in contrast to the homogeneously aligned cell showing the distinct threshold behavior.

The nematic LC material used in this work was MLC-6012 of E. Merck. The ordinary and extraordinary refractive indices of MLC-6012 are and respectively. Here, is the wavelength of the incident light in nanometers. The dielectric anisotropy and the elastic constants are and respectively. The chiral dopant of S-811 was introduced into the LC to produce a helical structure. The doping concentration was adjusted to give , where and 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 thick. A He–Ne laser of 632.8 nm was used as a light source for measuring the EO properties of our multimode transflective LC cell. All the measurements were carried out at room temperature.

Figure 3 shows microscopic textures of our two-mode transflective LC cell observed with a polarizing optical microscope (Nikon, Optiphot II) under crossed polarizers. In this case, no chiral dopant was used to distinguish between the homogeneous and hybrid aligned 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. It should be noted that the phase retardation through the homogeneous region is approximately twice as large as that through the hybrid region. Under the applied voltage of 10 V, no light is transmitted through the LC cell and thus a complete extinction was achieved in both the homogeneous and hybrid regions as shown in Fig. 3(b) since the dielectrically positive LC is aligned perpendicular to the substrate.

The transmitted and the reflected intensities in our multimode transflective LC cells are shown as a function of the applied voltage in Fig. 4. Here, the open circles and the open rectangles denote the experimental results of the transmitted and the reflected intensities, respectively. It is noted that the Frederiks transition was observed in the homogeneously aligned region while no transition was present in the hybrid region. As shown in Figs. 4(a) and 4(b), there is no appreciable difference in the transmittance between the case of and that of . In fact, above , a π-twisted configuration is more stable than a uniformly aligned configuration. For , 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. 4(b). Clearly, the EO disparity between the transmis-
sive and the reflective regions was significantly reduced by introducing a chiral dopant into the LC.

In summary, 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 was proposed. The two mode-transflective LC structure was prepared using a self-masking process of photoalignment which requires no additional process such as slit-reflector fabrication. 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 presence of the helical twisting power in the reflective HAN region.

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FIG. 4. The EO characteristics of our two-mode transflective LC cells for (a) $d/p = 0.0$ and (b) $d/p = 0.25$. The open circles and the open rectangles denote the experimental results of the transmittance and the reflectance for $d/p = 0.0$ and $d/p = 0.25$, respectively.