High Performance Optically Isotropic Liquid Crystal Display using Twisted Liquid Crystals for Flexible LCDs

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Abstract

Optically isotropic polymer/liquid crystal (OILC) composite film in which nano-sized liquid crystal droplets are embedded in a polymer matrix with minimal scattering is proposed for flexible LCDs with high contrast ratio, fast response time and wide-viewing-angle. Feeble light scattering in conventional OILC is overcome utilizing cholesteric LC but limiting its pitch larger than LC droplets, giving rise to higher contrast ratio. In this paper, we reports on electro-optic studies of OILC cells having various pitch sizes, exhibiting an outstanding dark state and improved transmittance.

Author Keywords

Optically isotropic liquid crystal; twisted liquid crystal; chiral dopant; transmittance; flexible LCD

1. Introduction

In current years, an optically isotropic liquid crystal (OILC) display with a fast response time and a wide viewing angle without an alignment layer has been actively studied, in order to realize flexible LCDs [1, 2]. In the present situation, there are two approaches showing an optically isotropic phase either polymer-stabilized blue phase liquid crystal (PS-BPLC) and nano- polymer dispersed liquid crystal (nano-PDLC). The PS-BPLC exhibited very fast response time and wide-viewing-angle; however, it has several problems such as a high operating voltage, and high electro-optical hysteresis [3-5]. Considering such disadvantages of the PS-BPLC, the nano-PDLC is relatively simple binary system in which nano-sized LC droplets was obtained by the well-adopted polymer induced phase separation method (PIPS). In nano-PDLC, the LC droplets possibly with bipolar orientation are randomly dispersed in the polymer matrix with its size below the visible wavelength regime i.e. >350 nm [6-8]. According to the scattering theory, the light scatters when an incident light experiences changes in the refractive index of the medium on the light path or faces larger particle size in which the Rayleigh theory does not applicable. However, in the case of much smaller particles than the wavelength of the light, the light passing through the phase experiences no scattering, and the Rayleigh-Gans theory is applicable. The scattered light can be explained as [9],

$$\sigma_{avg} \propto (m-1)^2\, k^4\, R^6$$

where m is the ratio between the refractive indexes of the nematic LC to the polymer matrix (n_{LC}/n_P), k is the wave number ($2\pi n_P/\lambda$), n_P is the refractive index of the polymer and R is the radius of the LC droplet. Therefore if m is equal to 1, ideal case, i.e. the effective refractive index of LC and polymer matches there is no light scattering, giving rise to a perfect dark state. In reality, R should be much smaller than λ to minimize a light scattering. However, reducing R would increase in an operating voltage such that the perfect dark state and low operating voltage are in a trade-off relation, intrinsically.

In field-ON state, the LC droplets are reorienting along the field direction giving rise to the induced birefringence, and thus the effect could be described as Kerr effect $\Delta n_{ind} = K\lambda E^2$, where K is the Kerr constant, λ is the wavelength of the light, and E is the applied electric field.

The foremost advantage of nano-PDLC is relatively easy fabrication compared to PS-PBLC. However, there are few drawbacks including non-zero light scattering which gives rise to relatively low contrast ratio. In this report, we attempted to obtain an efficient dark state and high contrast ratio OILC phase by utilizing the chiral dopant in the nano-PDLC system. The chiral dopant induces twist orientation of LC molecules inside the droplet and reduces the mismatch between the effective refractive index of LC and refractive index of the polymer.

2. Experiment and Result

The schematic switching mechanism of an OILC device with pure nematic LC (pure-OILC) along with the twisted nematic LC (twisted-OILC) at field OFF state has been demonstrated in Figure 1(a) and (b), respectively. In both devices, the embedded LC molecules are confined in the form of nano-sized droplets. The size of embedded LC droplets with random orientation is mostly below the visible wavelength regime but according to our previous studies, the SEM image of polymer network shows few droplets are larger than the visible wavelength region i.e. >300 nm, which might cause strong light scattering [10]. Therefore, although the device exhibits an optically isotropic state in the visible light and appears to be dark under the crossed polarizers, the achieved dark level is not still a pure black. In addition, the average refractive index of LC molecules (n_{LC}) in the pure-OILC is not equal to the refractive index of polymer matrix (n_p) because the LC molecules in each droplet might show a bipolar structure which are arranged parallel to the surface of the droplet, as shown in Fig. 1(a). As a result, the small amount light leakage is fundamentally generated due to slight refractive index mismatch along with various sizes of the LC droplets in visible wavelength region and the light scattering is maximized when the LC director of a droplet orients parallel to substrate because the difference between n_{LC} and n_p is maximal. On the other hand, the twisted-OILC may show reduced scattering because the difference between n_{LC} and n_p is much reduced by introducing the randomly twisted structure to the LC molecules within a confined LC droplet. Therefore, the twisted LC molecules replace the bipolar structure in the LC droplet as shown in Fig. 1(b). When the voltage is applied to both devices, the LC molecules reorient along the field direction due to either the Kerr effect [11, 12] or molecular orientations [13], so that an optical birefringence is induced, resulting in a bright state. However, we expect a slight increase in an operating voltage in the twisted-OILC because an additional electrical energy to unwind twisted LC is required. Therefore we need to optimize a pitch length and minimal length might be larger than LC droplet size.

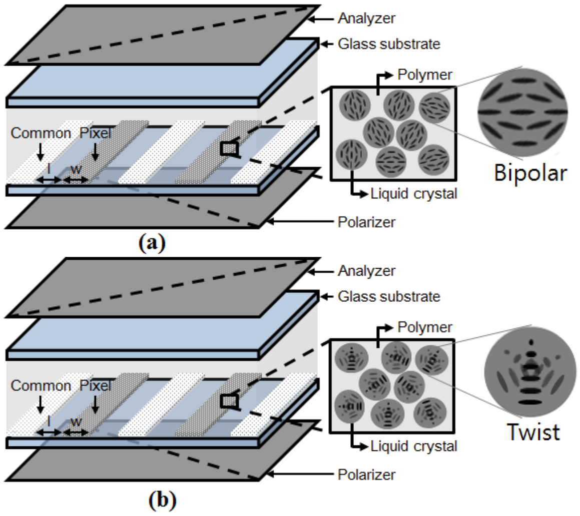

Figure 1. Schematic diagram of the cell structure and orientation of LC molecules of the OILC device using (a) pure nematic LC and (b) twisted LC at voltage-off state (optically isotropic state).

The prepared OILC composites consist of a nematic LC with high dielectric constant and birefringence (MLC2053, $\Delta\varepsilon = 46.2$, $n_e = 1.7472$, $n_o = 1.5122$, $\Delta n = 0.235$ at 589.3 nm, 20ºC, from Merck Advanced Technology in Korea), UV light curable photopolymer (Norland Optical Adhesive 65 (NOA65), $n_p = 1.524$, from Norland Products Inc.), and photo initiator (Irgacure651, from Ciba). The concentration of MLC2053 and NOA65 is maintained to be 40:60 wt% and a chiral dopant (SRM17, HTP = 166 μm^{-1}) was added with different concentration to induce twisted orientation to nematic LC. The measured pitch is 0.5 µm, 1 µm, and 2 µm for 1.2, 0.6, and 0.3 wt% concentration of chiral dopant, respectively. The mixtures were injected into the in-plane switching (IPS) cell by capillary force at 86 ºC. In order to obtain a high transmittance the cells were irradiated at different UV intensities and characterized as a function of the degree of phase separation. The electrode width and electrode distance were both 4 µm and the cell gap was fixed to 10 µm. The polarized optical microscope (POM), Nikon ECLIPSE E600 (Nikon, Japan) equipped with Nikon DXM 1200 digital camera, was used to characterize optically isotropic phase under crossed polarizers. The electro-optical properties were measured as a function of the voltage by using a lab-made set-up under crossed polarizers. The field applied to the sample by using a function generator (Agilent 33521A) and transmitted light was detected by photo detector and oscilloscope (Tektronix DPO 2024B).

The POM images are taken under crossed polarizers while keeping the backlight intensity unchanged for all over the measurement as shown in Fig. 2(a). The measured intensity of dark state or the relative light leakage is 50.5 for pure-OILC and 14.7, 12.9, and 1.0 for twisted-OILC with a pitch of 2 µm, 1 µm, and 0.5 µm, respectively. The light leakage was reduced to three times in twisted-OILC and also suggests that the obtained OILC films using twisted nematic LC are relatively free from light scattering. Obtained results are from the OILC cells which are irradiated with a low intensity of 25mW/cm^2 for the 60s. Figure 2(b) shows macroscopic images of cells, thus images show decrease in the scattering as decreasing in pitch, in which the pure-OILC shows noticeable scattering while the twisted-OILC shows considerably less scattering. In twisted-OILC, the cell with a pitch of 0.5µm showed the least or no scattering.

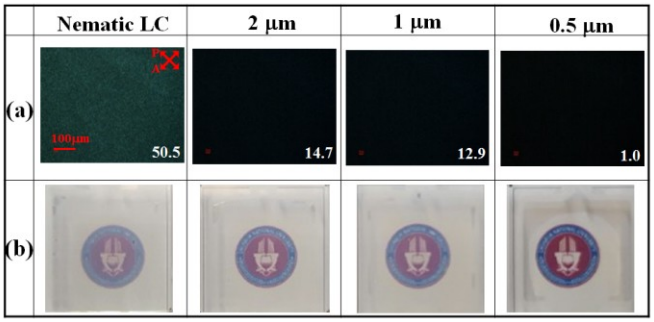

Figure 2. (a) POM images with crossed polarizers and (b) macroscopic images without crossed polarizers of all pure-OILC and twisted-OILC with a pitch of 2, 1, and 0.5 µm, respectively, at voltage-off state. Represented numbers on the dark images (top row) indicate that the light leakage from the sample.

For better understanding of the OILC, the OILC cells were irradiating with a high UV intensity of 150 mW/cm^2 for 10 s. Figure 3(a) shows the POM switching images of the dark and bright state in all pure-OILC and twisted-OILC cells with a pitch of 1 µm and 0.5 µm, respectively.

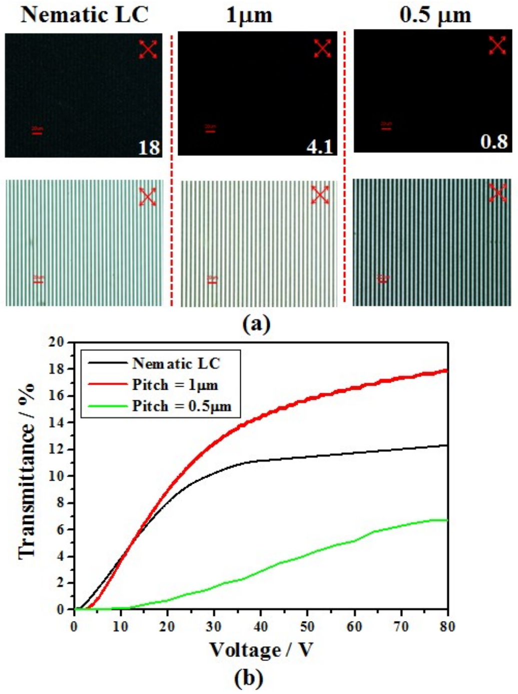

Figure 3. (a) POM images of dark and white states and (b) voltage-dependent transmittance curves in all OILC cells using nematic LC and twisted LC with a different pitch. Represented numbers on the dark images (top row in (a)) indicate that the light leakage from the sample.

In the dark state, the measured relative light leakage is 18 for pure-OILC and, 4.1 and 0.8 for twisted-OILC with a pitch of 1 µm and 0.5 µm, respectively. The higher twisted LC creates more randomness in the LC orientation which results to reduce in the refractive index mismatch between n_{LC} and n_p. Figure 3 (b) shows the voltage-dependent transmittance curves under crossed polarizers. To perform this experiment we used He-Ne laser with the wavelength of λ = 633 nm and the transmittance of light intensity was measured under the crossed polarizer. The obtained maximum transmittances are 12.3% for pure-OILC and 18% and 6.8% for twisted-OILC with a pitch of 1 µm and 0.5 µm, respectively. The twisted-OILC with a pitch of 1 µm shows an enhanced bright state and higher transmittance in comparison to the other pure-OILC and the twisted-OILC with a pitch of 0.5 µm. The twisted-OILC with a pitch of 0.5 µm shows least light leakage level but bright state and transmittance was decreased because it is difficult to make birefringence at low voltage due to short pitch in a confined LC droplet.

Figure 4 shows measured response time at constant square wave voltage of 80 V_{rms} with frequency of 1 kHz for pure-OILC and twisted-OILC cells with pitch of 1 µm and 0.5 µm, respectively. The measured rising and decaying times are the time elapsed for the transmittance to increase from 10% to 90% of maximum and the time elapsed for the transmittance to decrease from 90% to 10% of maximum, respectively. The rising times of all proposed twisted-OILC cells are slower than the pure-OILC because the twisted LC directors were unwound and then aligned along the applied field direction. However, in the case of decaying time, the twisted-OILC is faster than the pure-OILC because the LC director rotation and twisting angle would play a vital role to relax the LC molecule in a confined droplet. In addition, the decaying time is faster as the pitch is shorter.

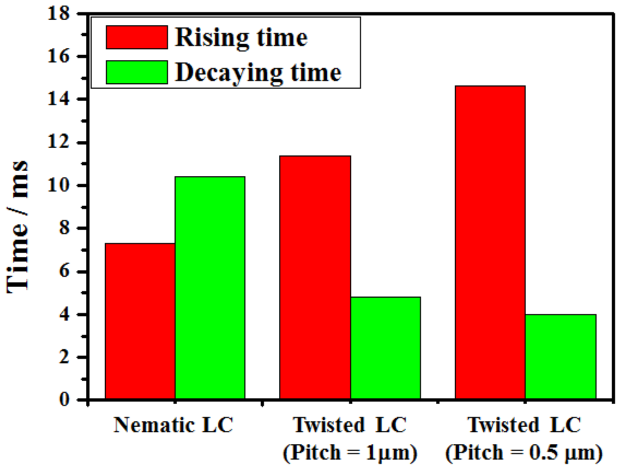

Figure 4. Rising and decaying times in all OILC cells using nematic LC and twisted LC with a different pitch.

To obtain high transmittance, we tailored various UV intensity of 150 mW/cm^2, 140 mW/cm^2, and 130 mW/cm^2 in twisted-OILC with a pitch of 1 µm sample. Herein, the twisted-OILC with pitch of 1 µm sample is characterized as a function of UV light intensity. Figure 5(a) shows POM images along with level of light leakage, obtained light leakage is 4 times efficient to the pure-OILC. In addition, in field ON state the transmittance of all proposed twisted-OILC cells are higher than the pure-OILC cell. The cell irradiated with intensity of 140 mW/cm^2 was shown highest transmittance i.e. increased by 49% as shown in Fig. 5 (b).

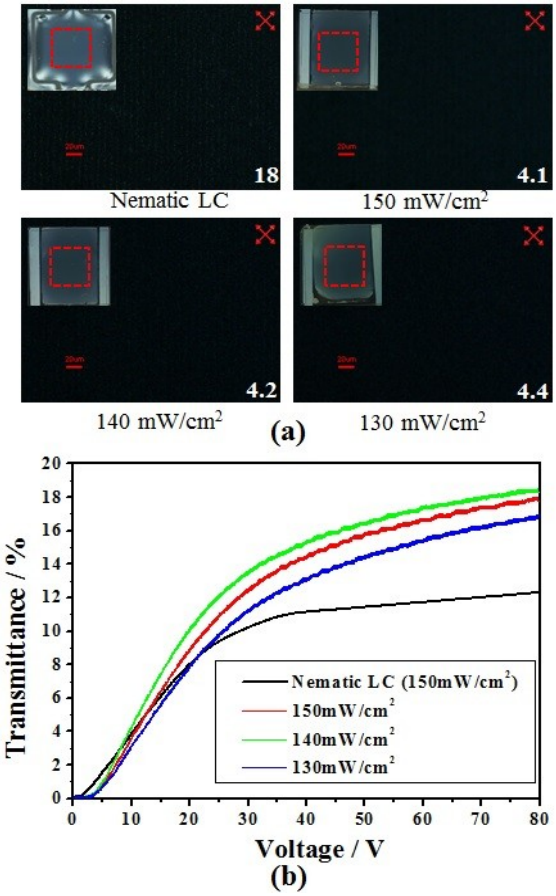

Figure 5. (a) POM images of dark states and (b) voltage-dependent transmittance curves in all OILC cells using nematic LC and twisted LC with a pitch of 1 µm according to different UV exposures. (The dark state images measure inside the dotted red box of macroscopic images and represented numbers inside the dark images indicate light leakage).

3. Conclusion

To obtain enhanced dark state level and high transmittance in pure-OILC mixture we proposed a twisted-OILC by adding chiral dopant with different pitch lengths to pure-OILC. The proposed twisted-OILC gives an outstanding dark state and faster decaying time for all pitch sizes and obtained higher transmittance in an optimal cell. The proposed device has a high potential in improving the contrast ratio of OILC, so the device to be applicable to the flexible display.

4. Acknowledgements

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