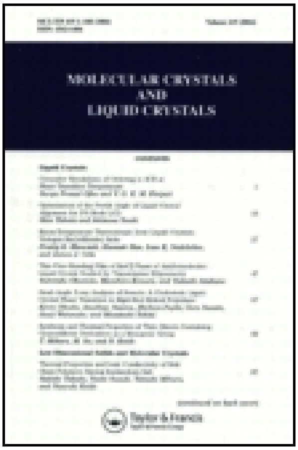

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Effect of Alignment Layer on Electro-Optic Properties of Polymer-Dispersed Liquid Crystal Displays

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The electro-optic properties of polymer-dispersed liquid crystal (PDLC) cell having parallel alignment layers were examined and compared to the control cell without any pre-treatment. Although the liquid crystal droplets of the treated PDLC was observed to be much smaller than that of the control cell, the contrast ratio of both cells are quite similar over a wide temperature range. The control cell performed better in terms of response time and operating voltage. The retardation characteristics of the cells showed sharp contrast, which may bring about inconsistent consequence in determining their electro-optic properties.

Keywords: alignment layer; contrast ratio; PDLC; retardation

INTRODUCTION

Polymer dispersed liquid crystal (PDLC) is a mixed phase of polymer and liquid crystal, which can be switched by applying an external electric field. Normally, PDLC is produced by photo-polymerization of a homogeneous mixture of monomers and liquid crystals. During the polymerization process, the mixture is separated into two difference phases of liquid crystal droplets and polymer phase due to the reduced solubility of liquid crystal in polymer matrix. PDLC has composite morphology in which LC droplets are distributed in polymer network. The interest in the material stems from the possible application to the electronic paper or the flexible display, which are believed to be the next generation display formats [1,2]. The liquid droplets are suspended by the polymer network so that the PDLC can preserve its

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shape. Also, unlike the conventional LCD, PDLC can modulate the light switching without alignment layer and polarizers, and hence provide a low-cost solution for flexible display. PDLC doesn't control the polarization state but the scattering of the input light. The largest scattering capability is obtained when the refractive index difference (Δn) between the LC molecules in a droplet ($n_{eff,\ LC}$) and the surrounding polymer phase ($n_{polymer}$). Therefore, PDLC made of LC having an ordinary index same as refractive index of polymer can produce a transparent state by arranging the director of LC droplet parallel to the incident light.

In the previous work, it was confirmed that the variation of measuring temperature could lead to wrong evaluation of PDLC cell performance [3]. As another important factor in achieving a decent PDLC, the surface treatment condition should be carefully considered. Especially the alignment layer, which is widely used in building a LCD cell, could provide a foreign polymer layer directly contacting PDLC.

In this work, two kinds of PDLC cells were fabricated, where one has parallel alignment layers (treated cell) and the other has no treatment (control cell), and the electro-optic properties were compared in order to find out the effect of alignment layer on PDLC performance.

EXPERIMENTALS

PDLC cell is prepared by sandwiching a mixture of pre-polymer and liquid crystal (TL205, Merck) between two transparent indium tin oxide (ITO) coated glass plates with 7 μm cell gap thickness. The detailed composition of pre-polymer studied is summarized in Table 1.

The mixture was introduced into the cell by the capillary action and photo-polymerized by illuminating with a UV lamp (365 nm peak wavelength) of 1 mW/cm^2 intensity for 10 minutes. During the UV curing, the temperature of the sample was fixed at 22°C using Linkam PE120 hot stage. The film has a typical PDLC morphology with domain sizes on the order of several μm in diameter.

TABLE 1 Composition of Pre-Polymers

	Monomer				
	EHA	BDVE	Cross – linker	Photo – initiator	Alignment layer
Treated	30	59	10	1	O
Control					X

Electro-optic properties were characterized using a linearly polarized 632 nm laser (Newport laser diode module, 5 mW) of 0.1 mW output power. By applying a gated 1-kHz sinusoidal voltage to the PDLC, the transmittance variation and the response time (defined as sum of rise and fall time) were measured. Rise and fall times are defined as the time for the transmitted light intensity to go from 10% to 90% (vice versa) of the maximum transmitted light intensity. The contrast ratio was calculated by dividing the measured on-state transmittance (T_{sat}) by off-state transmittance (T_o). The turn-on voltage of V_{90}, where the transmittance hits 90% of T_{sat}, is taken from the voltage-transmittance curve.

In order to examine the effect of the alignment layer on the electro-optic properties of PDLC's, the cell was implemented on the rotation stage and the twist angle of the sample, which is measured against the polarization axis of the incident laser beam, was controlled manually over 0 to 180°.

RESULTS AND DISCUSSION

Figure 1 shows optical micrographs of the two cells. It is very clear that the treated cell has LC droplets of 4 ~ 5 times smaller size compared to the control cell. This may be due to the existence of thin polymer layer having nano-patterns formed during the rubbing process. Those nano scale valleys can provide liquid crystal molecules with numerous nucleation sites so that LC domains distributes with much higher density in the treated cell.

Although the two cells have distinct difference in LC droplets size, the contrast ratio and response time were measured to be very similar. However, the operating voltage increased with the surface treatment

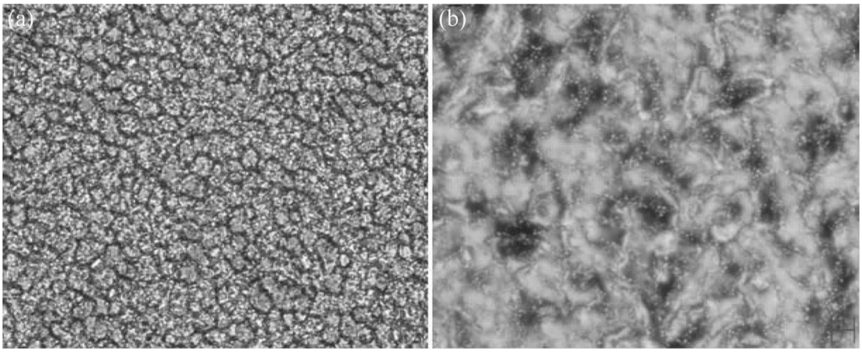

FIGURE 1 Optical micrographs of; (a) control cell, (b) treated cell.

as shown in Figure 2. In general, contrast ratio of PDLC decreases with increasing LC droplet size due to the reduced scattering volume. And also, the operating voltage of smaller LC domain is known to be lower

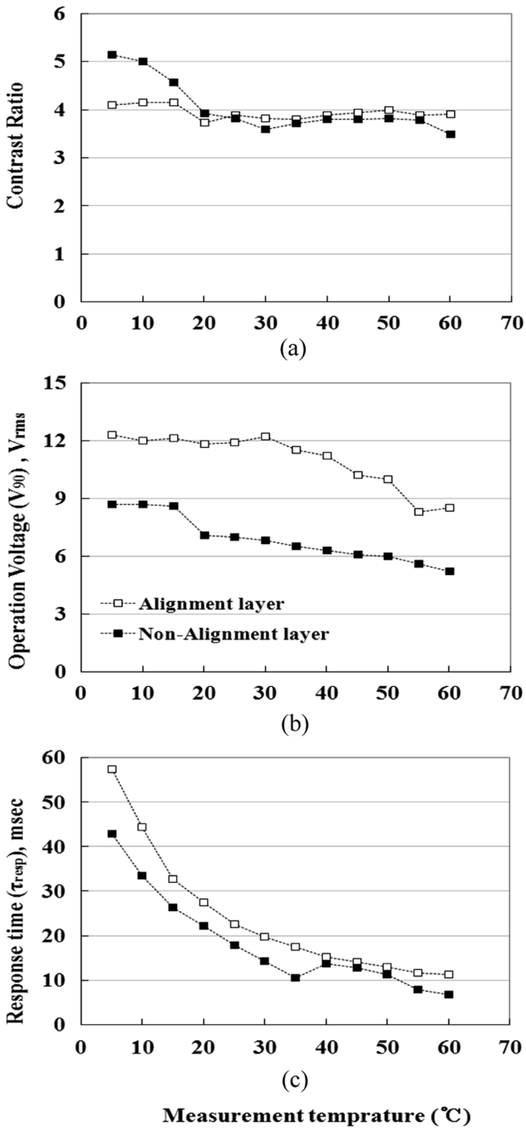

FIGURE 2 The effect of the alignment layer on temperature stability of; (a) CR, (b) operating voltage, (c) response time.

due to the smaller anchoring force, which is proportional to the interface area between polymer and liquid crystal domain. The inconsistency of the experimental result and the theoretical expectation is originated from the existence of the alignment layer, which should be considered as the second polymer phase together with the polymerized phase.

The effect of implementing an alignment layer is manifested by angular distribution of transmittance according to the sample rotation against the polarization axis of the laser. Figure 3(a) shows the variation of transmittance of the control cell. The transmittance doesn't change with the twist angle regardless of the electrical bias, which

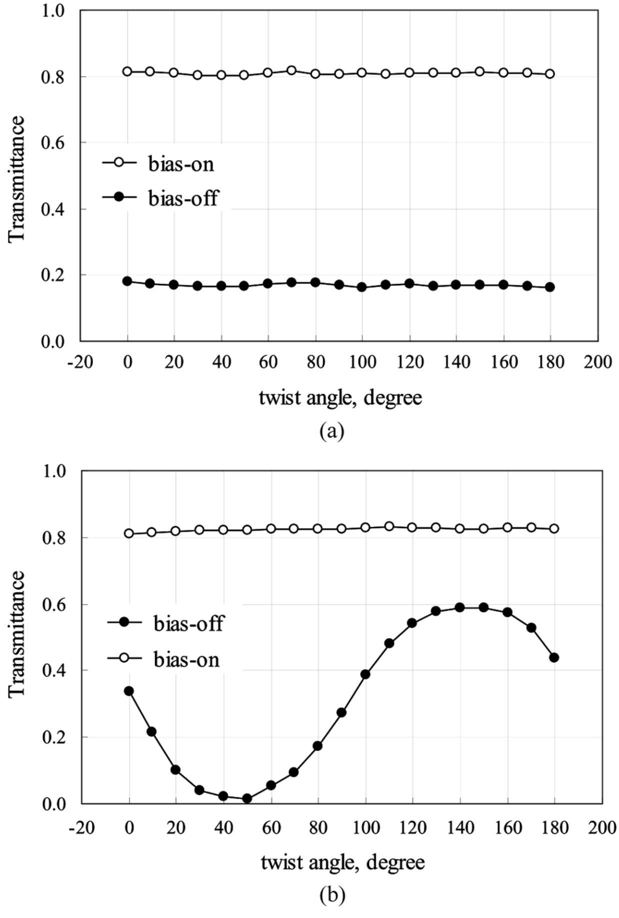

FIGURE 3 Transmittance variation with the samples rotation angle; (a) control, (b) treated.

means that the angular distribution of the refractive index is identical within the sample. As shown in Figure 4(a), the director of LC droplet distributes randomly so that the incident light will go through an optically isotropic media. Therefore, the scattering power is supposed to be identical regardless of the twist angle of the axis of the linearly polarized light and hence the contrast ratio. Under a bias, all the directors are aligned along the electrical field, which makes the index difference minimize. In this condition, the light is free to go through the media without showing any angular dependence.

However, the transmittance of the treated cell differs abruptly from the control cell. As shown in Figure 3(b), while the on-transmittance is same over the entire twist angle, the off-transmittance shows sinusoidal trend with 180° period. As mentioned earlier, this cannot happen in a PDLC having randomly distributed directors. That is, the directors should be aligned in a way that the polarization axis can run parallel with them at every 180°.

In general, the effective refractive index of LC droplet can be expressed as follows [4],

$$n_{eff}(\theta,\phi) = \frac{1}{\sqrt{\cos^2(\phi)\cdot\left[(\sin(\theta)/n_0)^2 + (\cos(\theta)/n_e)^2\right]}}$$

where, n_e, n_0, θ, and ϕ are the extraordinary index (1.744 for TL205), the ordinary index (1.5270 for TL205), the twist angle and the azimuthal angle, respectively.Considering PDLC as a birefringent media,

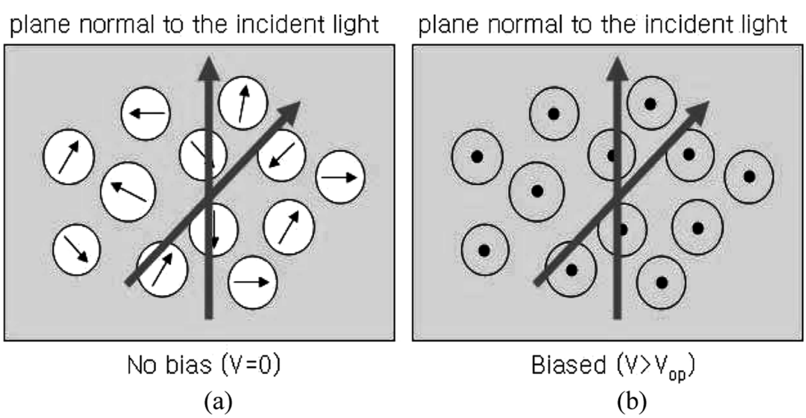

FIGURE 4 The relative arrangement of the linearly polarized light axis (gray arrows) and the directors of LC droplets; (a) under no bias and (b) under an electrical bias.

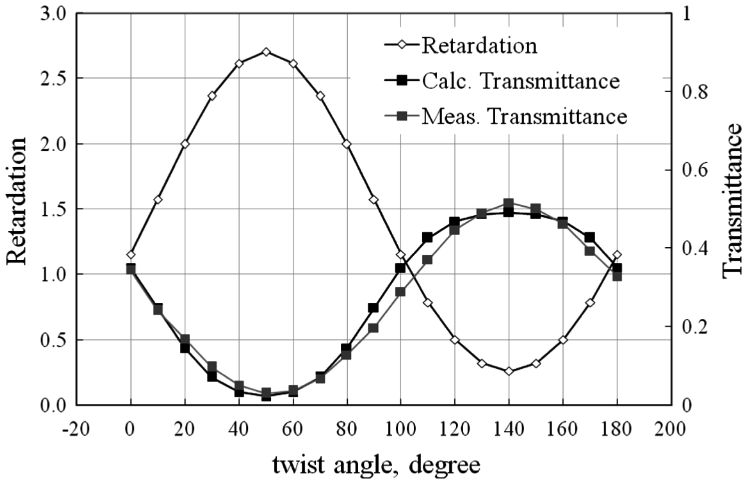

FIGURE 5 The variation of the calculated transmittance and the retardation with respect to the twist angle.

its retardation (rd) is given by the Eq. [5],

$$rd = \frac{2d\Delta n}{\lambda}$$

where, Δn is the index anisotropy of LC droplets (n_{eff}-n_0) and d is the thickness of PDLC layer. The transmittance varies with the retardation as follows [6],

$$T = \frac{1}{2}\cos^2(rd/2)$$

Using the two equations, the measured transmittance in Figure 5 was fitted by adjusting the index parameters and the azimuthal angle. The best fitted curves were obtained at $n_e = 1.7445$, $n_0 = 1.5270$, and $\phi = 10^\circ$, respectively. Therefore, it is safely confirmed that the directors of LC droplets are arranged to run parallel to the alignment direction.

CONCLUSIONS

The PDLC cell with a parallel alignment layer showed 4 or 5 times smaller LC domain compared to the untreated cell, however, similar trend of contrast ratio, operating voltage and response time in terms of temperature stability. The treated cell showed sinusoidal variation of transmittance of a polarized light with 180° period, which implies that the LC director is aligned along with the alignment direction. The off-transmittance of the treated cell was found to vary 0.03 to 0.58 with respect to the twist angle, which could make severe error in evaluating the contrast ratio value of a PDLC cell by a few orders of magnitude. Therefore, it is recommended that PDLC cell should be made without any alignment layer to secure wide viewing angle capability.

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