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Investigation of electro-optical characteristics of photo-aligned TN-LCDs on PCEMA surfaces

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In this work, a novel photo-alignment material, poly(cinnamolyethyl methacrylate) (PCEMA), was synthesized by photo-dimerization. We investigated the electro-optical characteristics of twisted nematic (TN)-liquid crystal displays (LCDs) photo-aligned with linearly polarized UV light irradiation at normal direction on the PCEMA surfaces. Excellent voltage–transmittance characteristics were observed. The threshold voltage of the photo-aligned TN-LCD decreases with increasing UV irradiation time. Additionally, response times are almost the same as for a rubbing-aligned TN-LCD.

1. Introduction

Most electro-optical (EO) applications of liquid crystal displays (LCDs) require a controlled monodomain alignment. LCDs with a pretilted homogeneous LC alignment are mostly prepared with rubbed polyimide (PI) surfaces. The leading technology for TFT (thin-film-transistor)-LCDs is based on the twisted nematic (TN)-LCD [1]; rubbed PI surfaces have been widely used to align the LC molecules. The effect of unidirectional rubbing on various alignment layers on surface alignment in a NLC has been demonstrated and discussed by many investigators [2–9]. However, the rubbing treatment creates several problems, such as the generation of electrostatic charges and the creation of contaminating particles. In a previous paper, we reported on the generation of electrostatic charges during rubbing on various alignment layers [10]. Thus rubbing-free techniques for LC alignment are required in TFT-LCD fabrication. The photo-alignment method for LC alignment is one of the most promising rubbing-free methods.

More recently, LC alignment by polarized UV light irradiation of poly(vinyl cinnamate) (PVCi) surfaces has been demonstrated [11–14]. Photo-polymerization of a photo-polymer with polarized UV light has been shown to induce uniaxial orientation of NLCs on poly(vinyl cinnamate) surfaces. The polar anchoring strength of a NLC on photo-dimerized alignment layers and rubbed PI surfaces has been reported by Shenoy *et al.* [15]. The detailed mechanism of LC alignment by photo-alignment is not yet well understood.

In this study, we report on the synthesis of the novel photo-alignment material poly(cinnamolyethyl methacrylate) (PCEMA) by photo-dimerization and the EO performance of the TN-LCD photo-aligned with linearly polarized UV light at normal direction on the PCEMA surfaces.

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2. Experimental

Figure 1 shows the chemical structure of PCEMA and PVCi used in this study. The polymers were coated on indium tin oxide (ITO) coated glass substrates by spin-coating, and were cured at 150°C for 1 h. The thickness of monomer layers was about 400 Å. The linearly p-polarized UV (power: 500 W) irradiation system is shown in figure 2. The substrates were irradiated for 30 s ~ 2 min using UV light at a wavelength of 365 nm.

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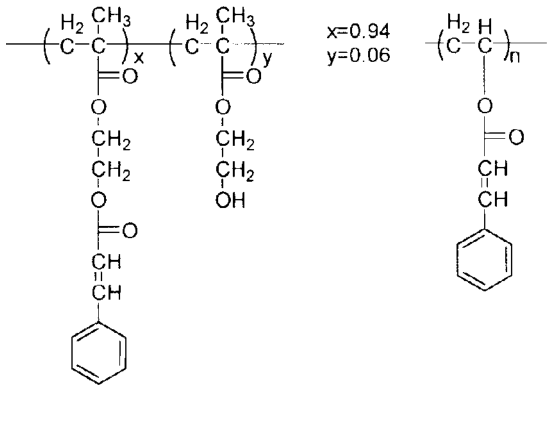

Figure 1. Chemical structure of (*a*) PCEMA and (*b*) PVCi.

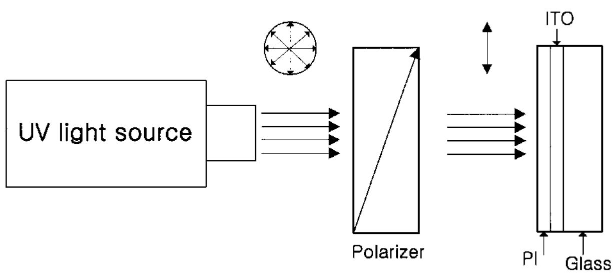

Figure 2. Schematic diagram of the UV irradiation system.

To measure the EO characteristics, the photo-aligned TN-LCDs were assembled using irradiation of the PCEMA and PVCi surfaces with linearly p-polarized UV light at normal direction. The LC layer thickness of the photo-aligned TN-LCD was 5 μm. A rubbing-aligned TN-LCD was fabricated at medium rubbing strength ($RS = 187$ mm) for comparison with the photo-aligned TN-LCDs. We measured the voltage–transmittance (V–T) characteristic and response times for the photo- and rubbing-aligned TN-LCDs.

3. Results and discussion

The photomicrographs of TN-LCD on PCEMA surfaces photo-aligned with linearly p-polarized UV light at normal direction (in crossed Nicols) for 2 min are shown in figure 3. Monodomain alignment of NLC was observed.

Figure 4 shows the voltage–transmittance characteristics of TN-LCDs on photo-aligned PCEMA and PVCi surfaces. The V–T characteristic for PVCi (30 s irradiation time) was not good; but an excellent V–T curve for the photo-aligned PCEMA surface (30 s) was observed. The V–T characteristic for the PCEMA surfaces is improved by increasing the UV irradiation

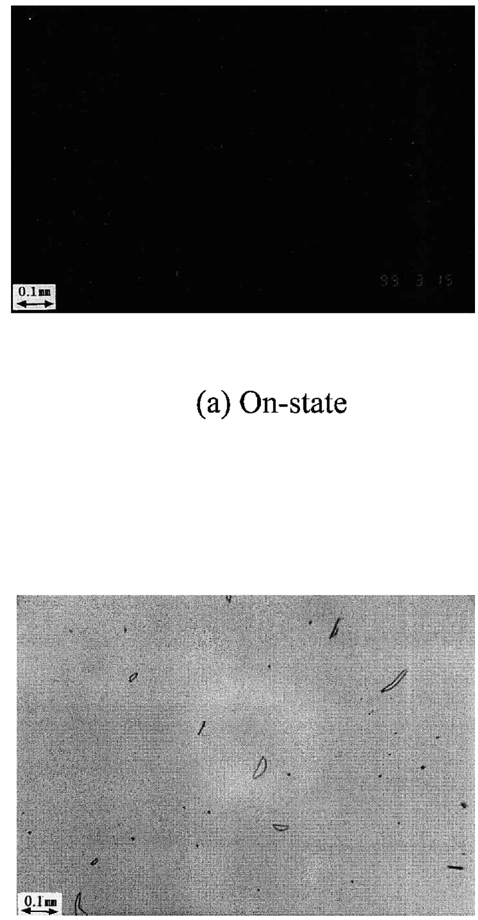

Figure 3. Photomicrographs of TN-LCD on PCEMA surfaces photo-aligned with linearly p-polarized UV light at normal direction for 2 min (in crossed Nicols): (*a*) on-state, (*b*) off-state.

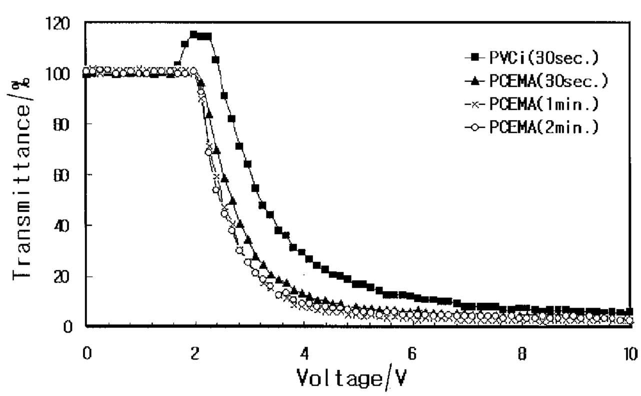

Figure 4. Voltage-transmittance characteristics of TN-LCDs photo-aligned on PCEMA or PVCi surfaces with linearly p-polarized UV irradiation at normal direction.

time. This is similar to the characteristics of a TN-LCD using photo-depolymerization and photo-aligned with unpolarized UV light on PI surfaces [16]. Table 1 shows the threshold voltage of TN-LCDs photo-aligned on PCEMA or PVCi surfaces with linearly p-polarized UV irradiation at normal direction. An excellent threshold voltage for a PCEMA surface (2 min irradiation) was obtained. This threshold voltage is almost the same as found with the rubbing-aligned TN-LCD.

The response time characteristics for PCEMA or PVCi surfaces at an applied voltage $V = 7$ V are shown in figure 5. Excellent curves for the TN-LCD photo-aligned on PCEMA (1 min) and PCEMA (2 min) surfaces were observed in the decay time characteristics; no backflow effect was observed. The response time characteristic is improved by increasing the UV irradiation time.

Table 2 shows response times for TN-LCD photo-aligned on PCEMA and PVCi surfaces. A fast response time, 28.8 ms, for the PCEMA (1 min) surface was observed. The response time of the photo-aligned TN-LCD is close to that of the rubbing-aligned TN-LCD. In a previous paper, Shenoy *et al.* reported that the polar anchoring energy of a NLC on a photo-dimerized monolayer is about 4.9×10^{-3} J m^{-2}, indicating a strong anchoring strength [15, 17]. From these results, we consider that the fast response time of the photo-aligned TN-LCD on a PCEMA (1 min) surface can be attributed to a strong anchoring energy between the LC molecules and the substrate surfaces.

Table 1. Threshold voltages of various photo-aligned and rubbing-aligned TN-LCDs.

Orientation film	V_{90}/V	V_{10}/V
PVCi (30 s)	2.68	6.41
PCEMA (30 s)	2.16	4.35
PCEMA (1 min)	2.10	3.76
PCEMA (2 min)	2.10	3.93
Rubbed PI	1.99	3.39

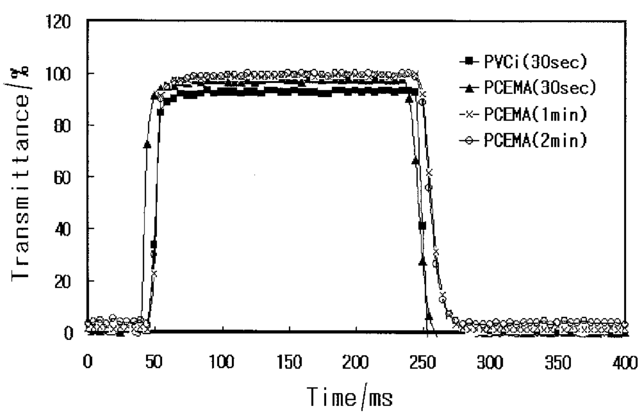

Figure 5. Response time characteristics of TN-LCDs photo-aligned on PCEMA and PVCi surfaces by irradiation with linearly p-polarized UV light at normal direction.

Table 2. Response times of various photo-aligned and rubbing-aligned TN-LCDs.

Orientation film	Rise time τ_r/ms	Decay time τ_d/ms	Response time τ/ms
PVCi (30 s)	16.0		
PCEMA (30 s)	9.2		
PCEMA (1 min)	6.8	22.0	28.8
PCEMA (2 min)	11.2	23.2	34.4
Rubbed PI	8.4	26.0	34.4

Consequently, we suggest that the EO characteristics of TN-LCDs photo-aligned on PCEMA surfaces with linearly p-polarized UV light at normal direction are strongly dependent on the UV irradiation time.

4. Conclusions

In summary, the novel photo-alignment material PCEMA was sythesized by a photo-dimerization reaction. Excellent voltage–transmittance characteristics for photo-aligned TN-LCDs on PCEMA surfaces were observed. The threshold voltage of a photo-aligned TN-LCD on a PCEMA (1 min) surface is about 2.1 V, almost the same as that of a rubbing-aligned TN-LCD. Finally, the response times of a photo-aligned TN-LCD on PCEMA surface are almost the same as those of the rubbing-aligned TN-LCD.

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