Liquid Crystals
Publication details, including instructions for authors and subscription information:
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Online publication date: 06 August 2010

Liquid Crystals, 2000, Vol. 27, No. 8, 1045–1048

Electro-optical characteristics of photo-aligned TN-LCD on PM4Ch surface

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(*Received 6 August 1999; in final form 16 February 2000; accepted 22 February 2000*)

In this study, a photo-alignment material PM4Ch, poly(4-methacryloyloxychalcone), was synthesized. The electro-optical characteristics of a photo-aligned twisted nematic liquid crystal display (TN-LCD), with linearly polarized UV exposure at normal direction on a PM4Ch surface, were investigated. The NLC alignment was uniform. Excellent voltage–transmittance characteristics were obtained; a fast response time was also achieved. Reduction of d.c. voltage decreases with increasing UV exposure time.

1. Introduction

The surface alignment of liquid crystals (LCs) on treated substrate surfaces is a key technology in fabricating LC display (LCD) devices. Most electro-optical (EO) applications of LCDs require controlled monodomain alignment. LCDs with pre-tilted homogeneous LC alignment are mostly prepared by using rubbed polyimide (PI) surfaces. The effect of surface alignment in nematic (N) LC using various alignments layers and unidirectional rubbing has been demonstrated and discussed by many investigators [1–6]. However, the rubbing treatment creates several problems, such as generation of electrostatic charges and creation of contaminating particles; in a previous paper, we reported on the generation of electrostatic charges produced on various alignment layers during rubbing [7]. Thus rubbing-free techniques for LC alignment are required in LCD fabrication. Photo-alignment is the most promising rubbing-free method; methods proposed thus far are photo-dimerization [8–11], photo-isomerization [12], and photo-dissociation [13–16].

Recently, some researchers [8–11] have reported LC alignment with polarized UV exposure of poly(vinyl) cinnamate surfaces. It appears that the photo-dimerization reaction of a photo-polymer exposed to polarized UV has been observed to induce uniaxial orientation of NLCs on poly(vinyl) cinnamate surfaces. Recently, the synthesis of photo-alignment materials such as PMCh [poly(4′-methacryloyloxychalcone)], PMCh-F [poly-(4-fluoro-4′-methacryloyloxychalcone)], PVCi [poly(vinyl) cinnamate), and PMCi [poly(2-methacryloyloxyethyl cinnamate)] has been reported by Makita *et al.* [17]. We have also reported the synthesis of the photo-alignment material PCEMA [poly(cinnamolyethyl methacrylate)], and the EO performance of photo-aligned TN-LCD on PCEMA surfaces [18]. The polar anchoring strength of NLC on photo-dimerized alignment layers and rubbed PI surfaces has been reported by Shenoy *et al.* [19]. However, the detailed mechanism of LC photo-alignment is not yet well understood.

In this work, we report on the synthesis of the photo-alignment material PM4Ch, particularly, on the photo-dimerization reaction and EO performance of photo-aligned TN-LCD, with linearly polarized UV exposure at normal direction on PM4Ch surfaces.

2. Experimental

Figure 1 shows the chemical structure of the PM4Ch used in this study. The polymer was synthesized by the following method. In a 250 ml round bottom flask, 4-hydroxychalcone and triethylamine were dissolved in 2-butanone and cooled to between −5 and 0°C in an ice bath. Methacryloyl chloride solution in 2-butanone was then added dropwise while stirring and keeping the temperature between −5 and 0°C. After stirring at room temperature for 4 h the precipitated ammonium salt was filtered off. The organic layer was washed successively

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Liquid Crystals ISSN 0267-8292 print/ISSN 1366-5855 online © 2000 Taylor & Francis Ltd
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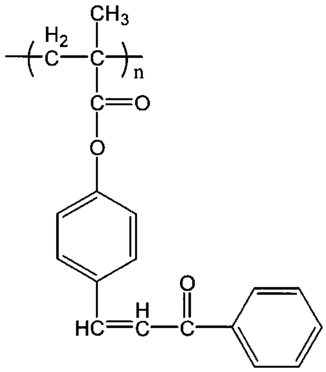


Figure 1. Chemical structure of PM4Ch.

with 5% aqueous sodium hydroxide solution and distilled water, dried over anhydrous magnesium sulfate and the 2-butanone evaporated. The product was purified by recrystallization from ethyl acetate/ethanol (1 : 1) mixture. Polymerization of monomers was carried out in solution in toluene, using 2,2′-azoisobutyro nitrile (AIBN) (2 mol %) as initiator at 70°C. The required amounts of monomers, initiator and toluene were mixed in a flask, and flushed with oxygen-free nitrogen for 30 min. After reacting for 48 h at 70°C, the polymer was precipitated with excess methanol. The crude polymer was purified by reprecipitation with methanol from chloroform solution, and was finally dried under vacuum.

The polymers were coated onto indium tin oxide (ITO) coated glass substrates by spin-coating, and were cured at 150°C for 1 h. The thickness of the polymer layers was 400 Å. The linearly polarized UV (Xe lamp, 500 W) exposure system is shown in figure 2. The substrates were irradiated for 30 s ~ 2 min. using 365 nm UV. To measure the EO characteristics, the photo-aligned TN-LCD was assembled after exposure of the PM4Ch surfaces with linearly polarized UV at normal direction, used with a 5 μm thick LC layer. The NLC used was a fluorinated-type mixture (T_c = 87°C). A rubbing-aligned TN-LCD was fabricated at medium rubbing strength (RS = 187 mm) for comparison with the photo-aligned TN-LCD. Measurement of voltage–transmittance, response time, and voltage–capacitance of the photo-aligned TN-LCD were carried out at room temperature.

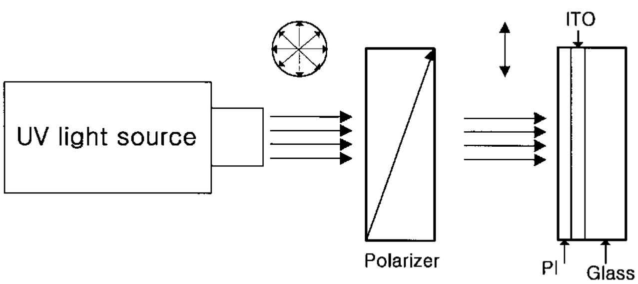


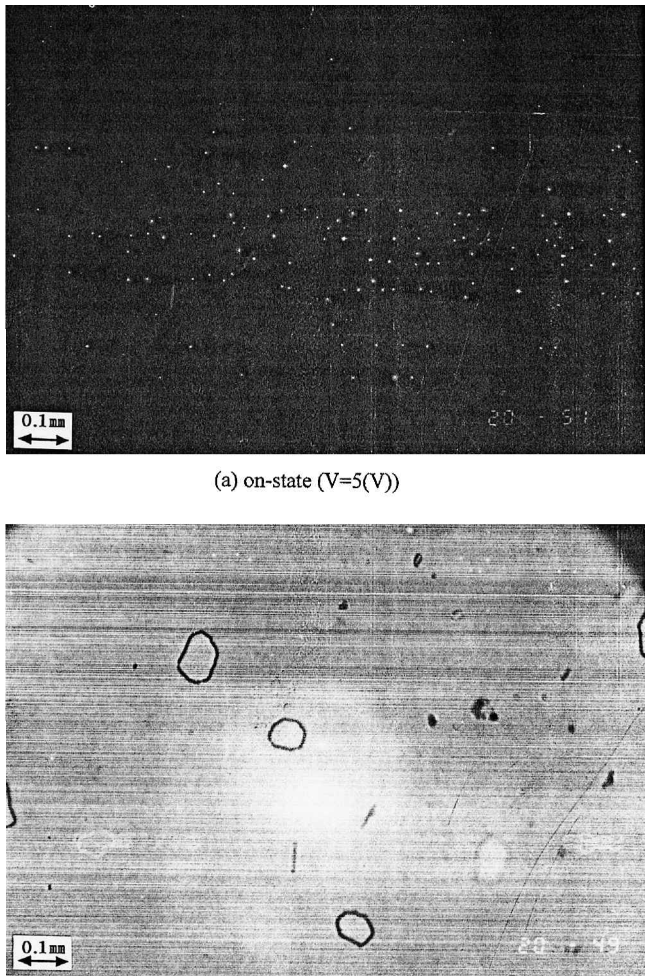
Figure 2. Schematic diagram of UV exposure system.

3. Results and discussion

Photomicrographs (in crossed Nicols) of a photo-aligned TN-LCD with linearly polarized UV exposure at normal direction on a PM4Ch surface for 1 min are shown in figure 3. The aligned NLC was relatively uniform.

Figure 4 shows the voltage–transmittance characteristics of the photo-aligned TN-LCD. Poor voltage–transmittance characteristics for 30 s and 2 min UV exposures were obtained; a 1 min exposure gave excellent results. Table 1 shows the threshold voltage of photo-aligned and rubbing-aligned TN-LCDs. The threshold voltage of the photo-aligned TN-LCD was almost the same as that of the rubbing-aligned TN-LCD.

The response time characteristics of a photo-aligned TN-LCD, with linearly polarized UV exposure at normal direction on PM4Ch surface, are shown in figure 5; an



(a) on-state (V=5(V))

(b) off-state

Figure 3. Photomicrographs of a TN–LCD photo-aligned with linearly polarized UV exposure at normal direction on PM4Ch surface for 1 min (in crossed Nicols): (*a*) on-state; (*b*) off-state. Applied voltage = 6 V.

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

Alignment	V_{90}	V_{10}
PM4Ch, 30 s	1.87	3.22
PM4Ch, 1 min	1.84	3.19
PM4Ch, 2 min	1.83	3.31
Rubbed PI	1.99	3.39

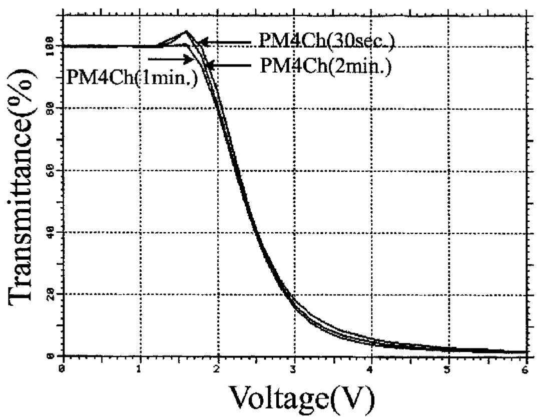


Figure 4. Voltage–transmittance characteristics of photo-aligned TN-LCD.

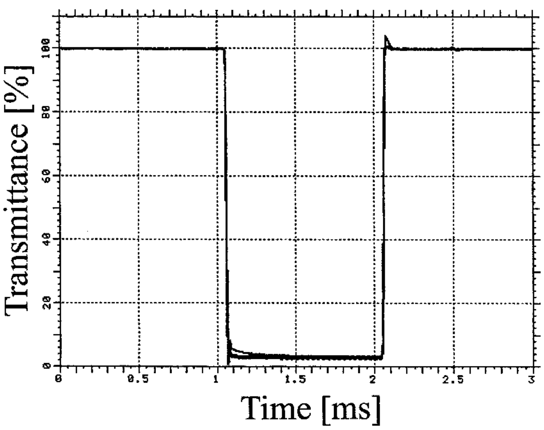


Figure 5. Response time characteristics of photo-aligned TN-LCD.

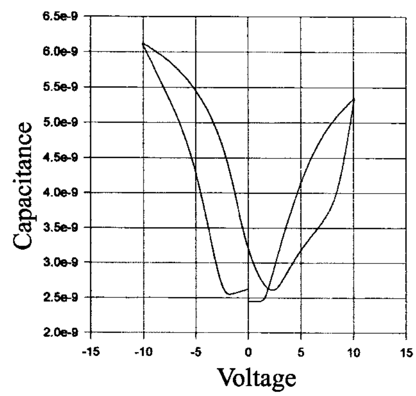
excellent curve is obtained. No backflow bounce effect was observed. Table 2 shows the response times for photo-aligned and rubbing-aligned TN-LCDs. It is seen that a fast response time (23.9 ms) for the photo-aligned TN-LCD (1 min UV exposure) was obtained; the response time of the photo-aligned TN-LCD was faster than that of the rubbing-aligned TN-LCD. In a previous paper, Shenoy *et al.* reported that the polar anchoring energy of NLC on a photo-dimerized monolayer is about 4.9×10^{-3} J m^{-2}, indicating a relatively strong anchoring strength [18]. From these results, we consider that

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

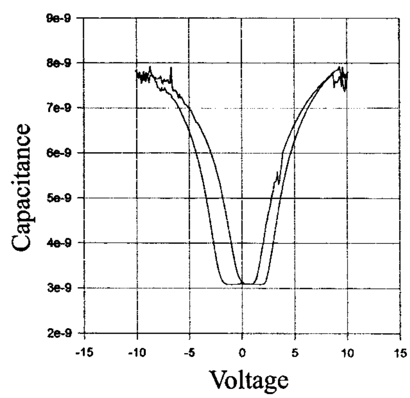
Alignment	Rise time /msec	Decay time /msec	Response time /msec
PM4Ch, 30 s	10.7	13.1	23.8
PM4Ch, 1 min	10.9	13.0	23.9
PM4Ch, 2 min	10.0	12.6	22.6
Rubbed PI	8.4	26.0	34.4

the fast response time of the photo-aligned TN-LCD can be attributed to a high anchoring energy between the LC molecules and the substrate surfaces.

Figure 6 shows the voltage–capacitance characteristics of a photo-aligned TN-LCD with PM4Ch surfaces. In figure 6 (*a*), the asymmetric voltage–capacitance characteristics of a photo aligned cell with 30 s UV exposure were measured; the characteristics of the photo-aligned TN-LCD are considered to be dependent on the inner



(a) PM4Ch(30sec.)



(b) PM4Ch(2min.)

Figure 6. Voltage–capacitance characteristics of photo-aligned TN-LCD: (*a*) 30 s UV exposure; (*b*) 2 min UV exposure.

ions of the LC cell. The reduction of d.c. voltage was observed to be about 3.5 V. The d.c. voltage reduction of a cell with 2 min UV exposure was measured at about 1.5 V, as shown in figure 6 (*b*). It is clear that the d.c. voltage reduction of photo-aligned TN-LCDs decreases with increasing UV exposure time.

4. Conclusions

In a summary, we have synthesized the photo-alignment material PM4Ch. The EO performance of photo-aligned TN-LCDs, with linearly polarized UV exposure at normal direction on PM4Ch surface, was studied. Uniform alignment of the NLC was obtained. Excellent voltage–transmittance characteristics were obtained, and fast response times were achieved. The d.c. voltage reduction of a photo-aligned TN-LCD decreases with increasing UV exposure of the PM4Ch surface, and thus depends on the alignment layer and cell conditions.

This work has been supported by a Grant for 98 Hackjegan Research (E00022) of the Korea Research Foundation.

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