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Response time mechanism for a photo-aligned vertical-alignment liquid crystal display on a homeotropic alignment layer

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The electro-optical characteristics of the photo-aligned vertical-alignment liquid crystal display (VA-LCD) with a non-polarized UV exposure of 45° on homeotropic polyimide (PI) surface was investigated. The domain size of the photo-aligned VA-LCD increases proportionately with the UV exposure time. The LC alignment of the photo-aligned VA-LCD is attributed to photo-dissociation of the polymer by UV exposure on the homeotropic PI surface. Good voltage–transmittance characteristics of the photo-aligned VA-LCD without negative compensation film was measured. The response time of the photo-aligned VA-LCD was slow compared with a rubbing-aligned VA-LCD; this is considered to be due to the alignment of LC molecules.

1. Introduction

Liquid crystal displays (LCDs) for desk top monitors are required to have a wide viewing angle, fast response time, high contrast ratio, and vivid colour performance. Thin film transistor (TFT)-LCDs are widely utilized for information displays in notebook computers, desk top monitors, and televisions because they have excellent resolution quality. However, TFT-LCD performance has been less than satisfactory due to narrow viewing angle and slow response times.

Various techniques to improve the viewing angle characteristics, have been developed, such as the addition of birefringence films [1], the domain-divided twisted nematic (TN) mode [2], the in-plane switching (IPS) mode [3], and the multi domain vertical alignment (MVA) mode [4, 5]. The MVA-LCD is expected eventually to achieve a wide viewing angle, fast response time, and high contrast ratio. However, the division of each pixel into multidomains and fringe fields is necessary for the MVA-LCD.

Most electro-optical (EO) applications of LCDs require a controlled monodomain alignment. Rubbed polyimide (PI) surfaces have been widely used to align LC molecules. The effect of surface alignment by unidirectional rubbing on nematic (N) LC in various alignment layers has been demonstrated and discussed by many investigators [6–12]. However, the rubbing treatment creates several problems, such as the generation of electrostatic charges and the creation of contaminating particles [13]. Thus, non-rubbing techniques for LC alignment are required in TFT-LCD fabrication.

More recently, LC alignment by using the photo-dissociation reaction of a PI surface with polarized [14–19], and non-polarized [20–22] UV light has been investigated. Yoshida *et al.* [23, 24], have reported on the EO performance of MVA-LCDs with non-polarized UV exposure of the homeotropic alignment layer. However, the detailed mechanism of the response time for the photo-aligned VA-LCD is not yet well understood. In this study, we report on the EO performance of photo-aligned VA-LCDs with a non-polarized UV exposure at 45° on homeotropic PI surfaces.

2. Experimental

In these experiments, the homeotropic polymer used was JALS688-R5 (Japan Synthetic Rubber Co., Ltd). The polymers were coated on indium tin oxide (ITO) coated glass substrates by spin-coating, and were then imidized at 180°C for 1 h. The PI layer thickness was about 400 Å. The non-polarized UV (power 500 W) exposure system is shown in figure 1. The homeotropic PI surfaces were exposed for 10, 20, and 30 min to UV light of wavelength 365 nm.

To measure EO characteristics, photo-aligned VA-LCDs were fabricated with an anti-parallel structure by non-polarized UV exposure on the alignment layer. The cells were injected with isotropic phase LC and cooled to room temperature. The LC layer was 4.25 μm thick; the NLC used having negative dielectric anisotropy. A rubbing-aligned VA-LCD was assembled at medium

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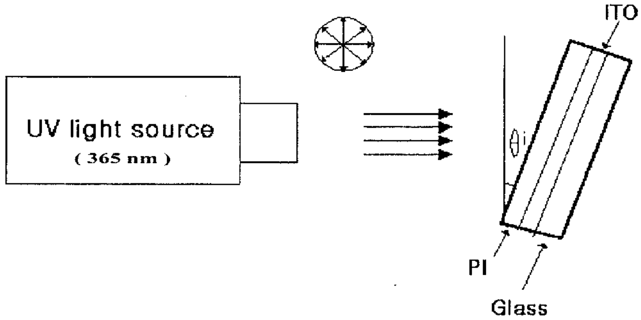


Figure 1. UV exposure system.

rubbing strength (164 mm) for comparison with the photo-aligned cell; a non-aligned VA-LCD was also assembled. We measured the voltage–transmittance and response time characteristics for the various VA-LCDs.

3. Results and discussion

Figures 2(*a*), 2(*b*), and 2(*c*) show photomicrographs of an on-state ($V = 6$ V) VA-LCD photo-aligned by non-polarized UV exposure at 45° on homeotropic PI surfaces. Monodomain alignment after UV exposure for 10 min is shown in figure 2(*a*). The LC alignment is attributed to photo-dissociation of the polymer. A small domain size was observed for a UV exposure time of 20 min; a large domain size was observed for a 30 min exposure. We consider the domain size of the photo-aligned VA-LCD increases with increasing UV exposure time; the domain size therefore depends on the photo-dissociation of the polymer.

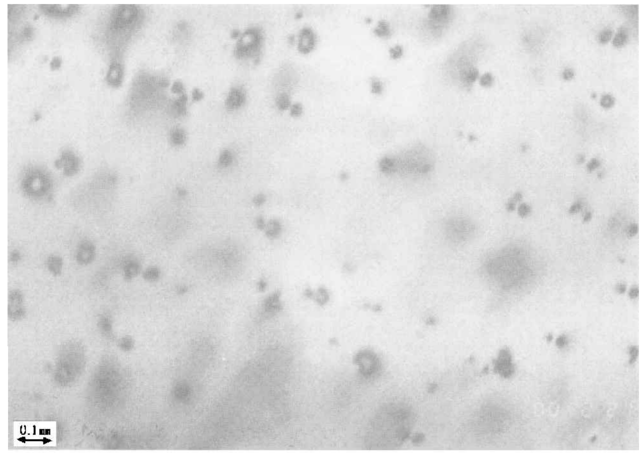
Photomicrographs of the rubbed and non-aligned VA-LCDs on homeotropic PI surfaces at on-state ($V = 6$ V) are shown in figure 3. Figure 3(*a*) shows the monodomain alignment of the rubbing-aligned VA-LCD. Large domains for the non-aligned VA-LCD were also observed, as shown in figure 3(*b*); it is considered that this can be attributed to iso-LC directing properties of the applied voltage. The domain size of the non-aligned VA-LCD was almost the same as the photo-aligned VA-LCD with a UV exposure time of 30 min.

Figures 4(*a*), 4(*b*) and 4(*c*) show the voltage–transmittance characteristics of the various VA-LCDs on homeotropic PI surfaces. The transmittance of the photo-aligned VA-LCD is almost zero at $V = 0$, and increases with applied voltage as shown in figure 4(*a*). The transmittance then saturates at about 6 V. Excellent voltage–transmittance characteristics for the photo-aligned VA-LCD are expected when negative compensation film is used; we suggest therefore that the transmittance of the photo-aligned VA-LCD may be attributed to the unidirectionally aligned LC molecules.

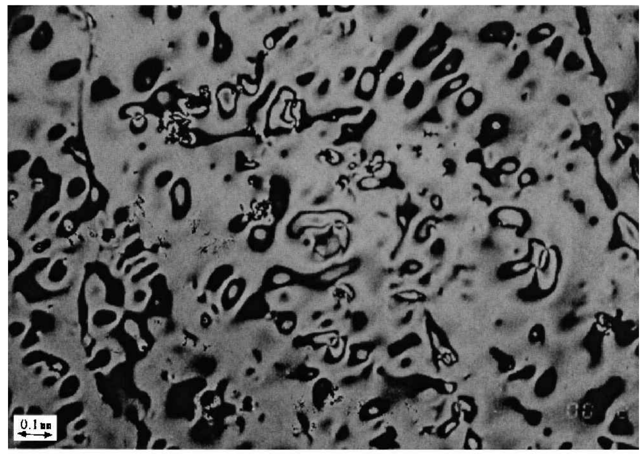
Good voltage–transmittance characteristics were also seen for the rubbing-aligned VA-LCD, figure 4(*b*). However, poorer voltage–transmittance characteristics were observed for the non-aligned VA-LCD, as shown in figure 4(*c*); the transmittance decreased with increasing applied voltage above 3 V. This transmittance is attributed to randomly-aligned LC molecules; unidirectionally alignment of the LC molecules is therefore required to achieve good voltage–transmittance characteristics.

Table 1 shows the threshold voltage for various VA-LCDs on homeotropic PI surfaces. The threshold voltage of the photo-aligned VA-LCD was almost equal to those of the rubbing- and non-aligned VA-LCDs.

Figures 5(*a*), 5(*b*) and 5(*c*) show the response time characteristics of various VA-LCDs on homeotropic PI surfaces. The response time for the photo-aligned VA-LCD was almost the same as for the rubbing-aligned

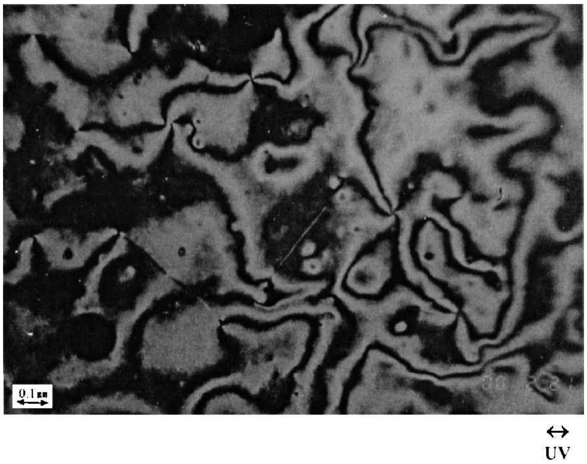


(a)



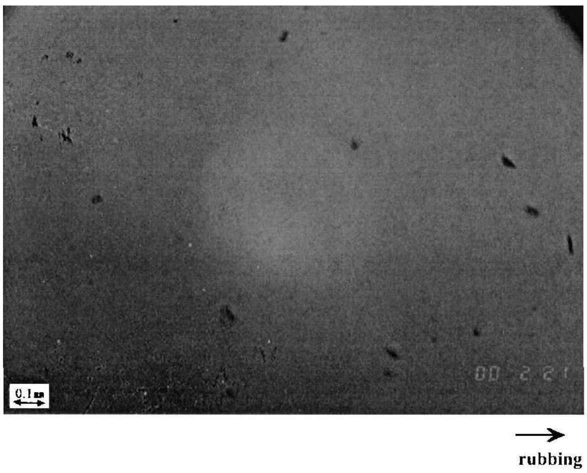
(b)

Figure 2. Photomicrographs for photo-aligned VA-LCD by non-polarized UV exposure for different times at 45° on homeotropic PI surfaces at on-state ($V = 6$ V): (*a*) 10 min, (*b*) 20 min, (*c*) 30 min.

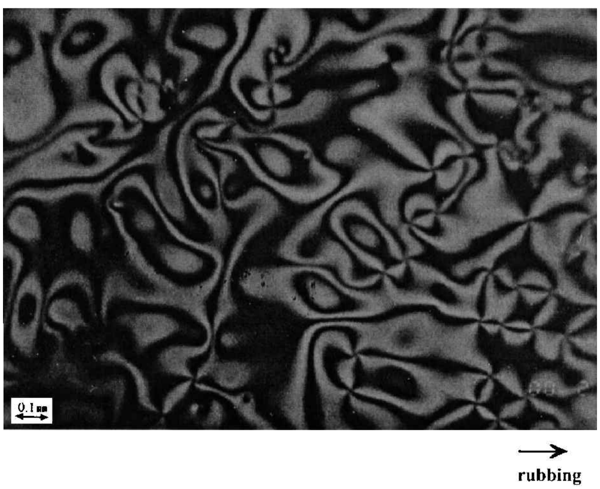


(c)

Figure 2. (*continued*).

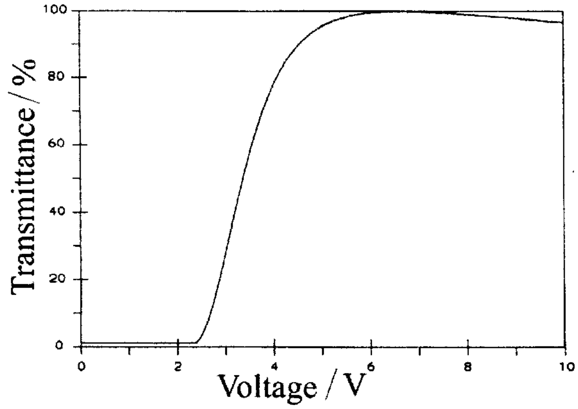


(a)

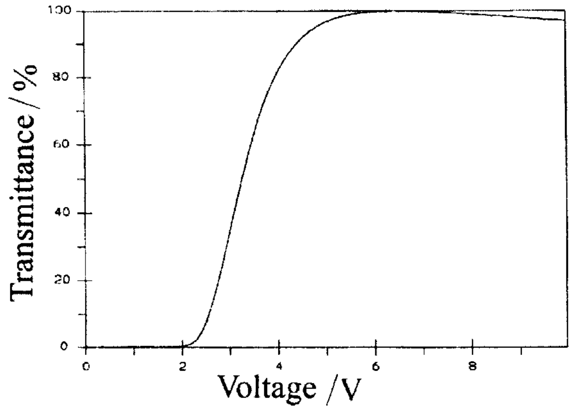


(b)

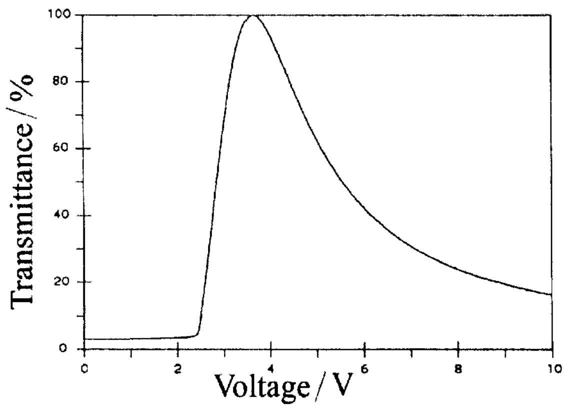
Figure 3. Photomicrographs for rubbing-aligned and non-aligned VA-LCDs on homeotropic PI surfaces at on-state ($V = 6$ V): (*a*) rubbing-aligned, (*b*) non-aligned.



(*a*)



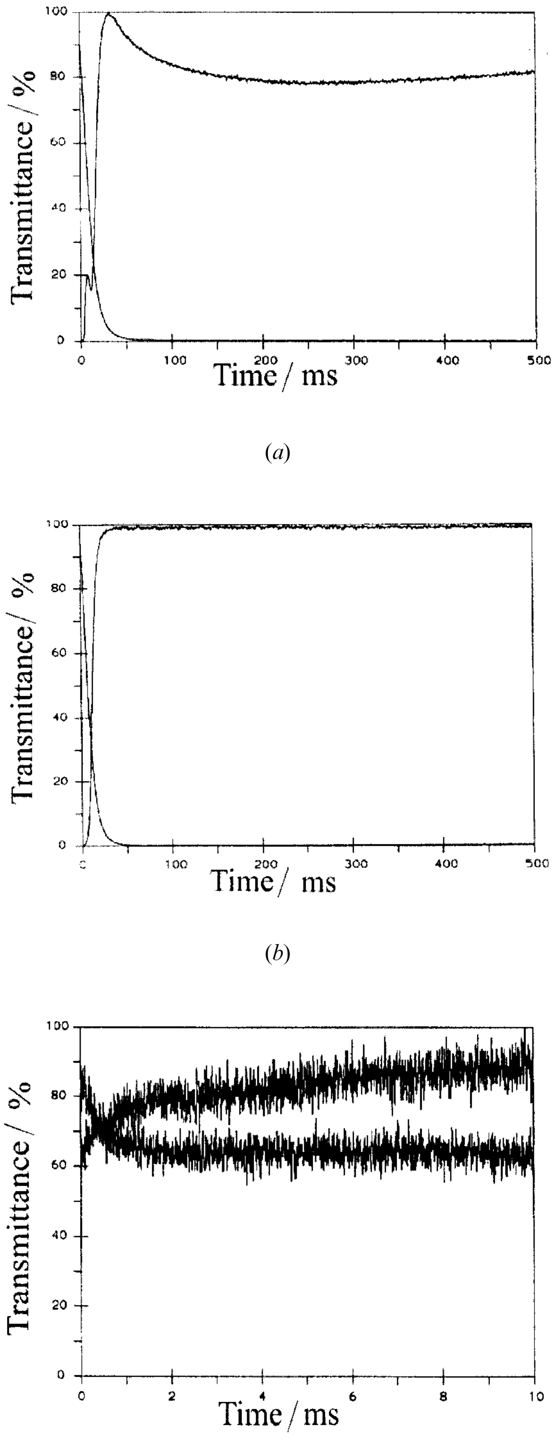
(*b*)



(*c*)

Figure 4. Voltage-transmittance characteristics of (*a*) photo-aligned (10 min UV) VA-LCD, (*b*) rubbing-aligned VA-LCD, and (*c*) non-aligned VA-LCD on homeotropic PI surfaces.

VA-LCD, as shown in figures 5(*a*) and 5(*b*). We believe that the transmittances could be increased by using negative compensation film. However, the response



(*a*)

(*b*)

(*c*)

Figure 5. Response time characteristics of (*a*) photo-aligned (10 min UV) VA-LCD, (*b*) rubbing-aligned VA-LCD, and (*c*) non-aligned VA-LCD on homeotropic PI surfaces.

time for the non-aligned VA-LCD was poor, as shown in figure 5 (*c*); this is attributed to random alignment of the LC molecules.

Table 1. Threshold voltages for various VA-LCDs on homeotropic PI surfaces.

LCD mode	V_{10}	V_{90}
Photo-aligned VA (10 min)	2.7	4.5
Photo-aligned VA (20 min)	2.66	4.57
Rubbing-aligned VA	2.56	4.39
Non-aligned VA	2.53	3.28

Table 2. Response times for various VA-LCDs on homeotropic PI surfaces.

LCD mode	τ_r/ms	τ_d/ms	τ/ms
Photo-aligned VA (10 min)	21.3	21.8	43.1
Photo-aligned VA (20 min)	26.7	16.4	43.1
Rubbing-aligned VA	18.2	18.5	36.7
Non-aligned VA	691	49	740

Table 2 shows the response times for the various VA-LCDs on homeotropic PI surfaces. The response time of the photo-aligned VA-LCD was measured at about 43 ms, slower than that of the conventional rubbing-aligned VA-LCD. We suggest that this is due to the domain alignment of the LC molecules. Also, a very slow response time was measured in the non-aligned VA-LCD; the response time of the photo-aligned VA-LCD is thus shown to depend on the alignment of LC molecules.

4. Conclusion

We have investigated the EO characteristics of VA-LCDs photo-aligned by non-polarized UV exposure at 45° on homeotropic PI surfaces. Good voltage–transmittance characteristics were seen without the use of negative compensation film. The response time is slow compared with rubbing-aligned VA-LCDs. We suggest that the slow response time of the photo-aligned VA-LCD can be attributed to alignment of the LC molecules.

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