A Study on Electro-optical Characteristics in Three Kinds of Liquid Crystal Display Operating Mode

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In this study, we investigated response characteristics of liquid crystal display (LCD) with different operating mode of nematic liquid crystals (NLCs) such as 45 ° twisted nematic (TN), 67.3 ° TN and electrical controlled birefringence (ECB) on the rubbed polyimide (PI) surface with side chains. The pretilt angles generated on polyimide surfaces of the three kinds of LCD operating modes were about 12 ° that was higher than those of conventional TN-LCDs. Also, the Electro-optical (EO) performance of these LCDs showed stable condition. Low transmittance of the 45 ° TN and 67.3 ° TN cell on the rubbed PI surface were measured by using low cell gap *d*. The fast response time in ECB cell among the three kinds of LCD operating modes was achieved. Also, thermal ability of fast 90 ° TN-LCD was investigated. The threshold voltage and the response time of thermal stressed TN-LCDs showed the same performances on no thermal stressed TN-LCDs. There was little change of value in these TN cells. However, the transmittances of TN-LCDs on the rubbed PI surface decreased while increasing thermal stress time. Therefore, the thermal stability of TN-LCD was decreased by the high thermal stress for the long duration.

Keywords : Transmittance, Response time, Polyimide (PI), Twisted nematic (TN), Δnd

1. INTRODUCTION

Recently, thin film transistor (TFT)-liquid crystal displays (LCDs) have been widely used in information display devices such as notebook computers, desktop monitors and car navigation systems. Liquid crystal modes such as in-plane switch (IPS)[1] optically compensated bend (OCB)[2], vertical alignment (VA)[3] are being researched for improving response time. Response time must also be shorter than the time of 1 frame to be used as HDTV for moving picture. In particular, it has been demanded within 10 ms at least to implement moving picture perfectly. So, fast response research using the nematic liquid crystal (NLC) is very important in LCD industry. There are many advances in viewing angle and color definition coming up to the acceptance level in the display market. However, these modes have the response time that is still not sufficiently fast for video displays, low yield ratio and high manufacture cost comparing with usual twisted nematic (TN) mode. Especially, it is critical that for the long duration, the function of the display should be maintained properly. So it is necessary to examine the problems coming from the long period display[4]. The major part of the study of the display stability is the thermal stability, above all, in the area of the projector type LCD. In the LCD projector and projection TV, the equipped 2 inch LCD panel enable the photo element to be enlarged for the display in it. This projector type of LCD has low brightness on the ground of actualization principle. Therefore, to improve brightness, much too strong source of light is needed and this will induce intensively high heat around, causing the characteristics of the LCD to be deteriorated. But, thermal stability of LCD is not reported yet. Therefore, we support that LCD cell used the LCD projector and projection TV should have quality for fast response and high thermal stability.

In this paper, we studied fast response time and transmittance of LCD operating modes using 45 °TN, 67.3 °TN and electrical controlled birefringence (ECB). In particular, we concentrated on EO characteristics according to different NLC and cell gap because refractive indices and cell gap affect to the response time of LCD. Also, this study is designed to investigate the electro-optic change of LCD when exposed to intense heat for the duration.

2. EXPERIMENTAL

In these experiments, the polymer (SE-7792, Nissan Chemical Industries Co.) with side chains was used as a homogeneous alignment layer and coated on ITO-coated glass substrates by spin-coatings, which were then imidized at 180℃ for 1 h. The thickness of the PI layers was 500 Å. The rubbing-free method was adopted for the patterned ITO electrodes. The PI films were rubbed by using a machine equipped with a nylon roller (Y_0-15-N, Yoshikawa Chemical Industries Co.). A definition of rubbing strength (RS) has been given in previous papers [6,7]. The RS used was 187 mm for the medium-rubbing region. The TN cell was used for the both-sides rubbed PI surfaces. The LC layer thickness of TN cells was set at 1.6 µm. NLCs in positive dielectric anisotropy are used. TN cells was fabricated at room temperature and annealed at 100℃ during 1 hr, 6 hr and 12 hr for the measurement of thermal characteristics. The TN cell fabricated was normally white (NW) mode. The voltage-dependent transmittance (V-T) and response time measurements were performed at room temperature (22℃). The pretilt angle of anti-parallel cell was measured by the crystal rotation method. The EO characteristics were measured by using the LCD evaluation system. (LCD 7000, Otsuka Co.)

3. RESULTS AND DISCUSSION

3.1 Fast response time according to operating mode

Figure 1 shows NLC pretilt angles on polyimide surfaces with side chain as a function of rubbing strength. As shown in Fig. 1, the pretilt angle of three kinds of LCDs generated on polyimide surface is about 12 ° at RS= 110 mm. These pretilt angles were higher than those of conventional TN LCDs. TN cells on rubbed polyimide (PI) surface show stable condition in regardless of rubbing strength. Table 1 shows refractive indices of nematic liquid crystals and cell gap according to rubbing condition.

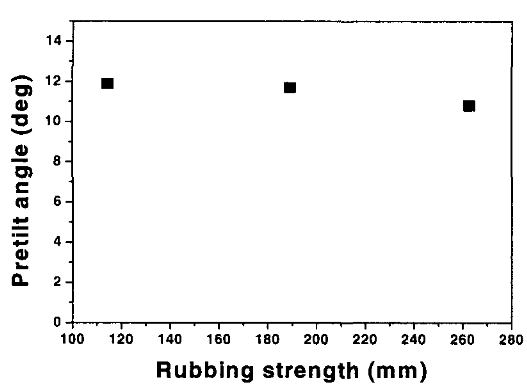
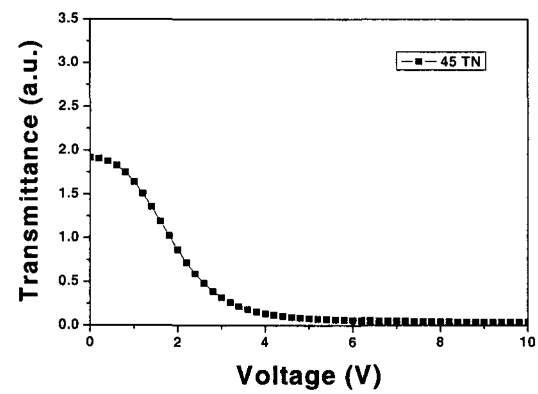


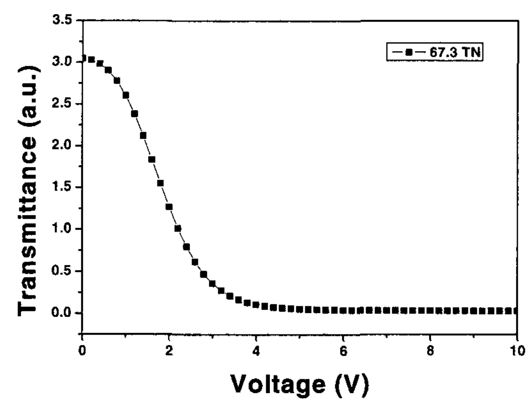
Fig. 1. NLC Pretilt angles on polyimide surfaces as a function of rubbing strength.

Table 1. NLCs and cell gap.

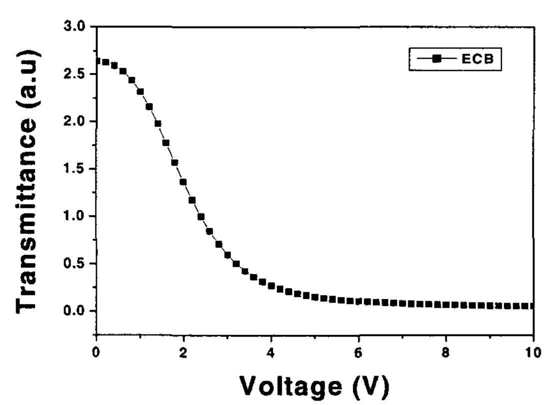
Type	Δn	d (µm)	Δnd
45 ° TN	0.105	1.6	0.168
67.3 ° TN	0.130	1.6	0.208
ECB	0.091	1.6	0.146



(a) 45 ° TN mode



(b) 67.3 ° TN mode

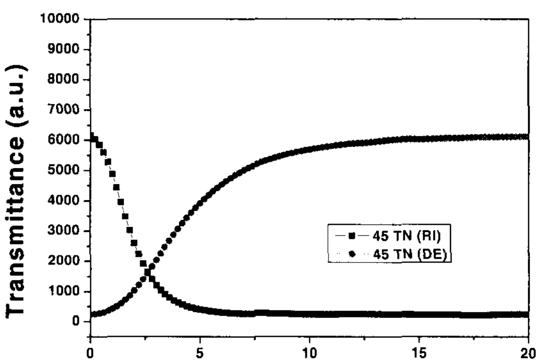


(c) ECB mode

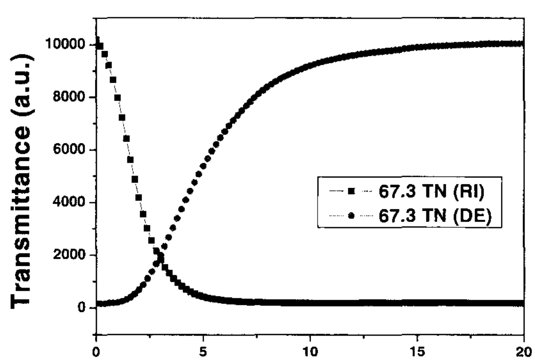
Fig. 2. V-T characteristics of the TN cell with Δnd of NLCs on the rubbing PI surface.

Table 2. Threshold voltages of the TN cell with Δnd of NLCs on the rubbing PI surface.

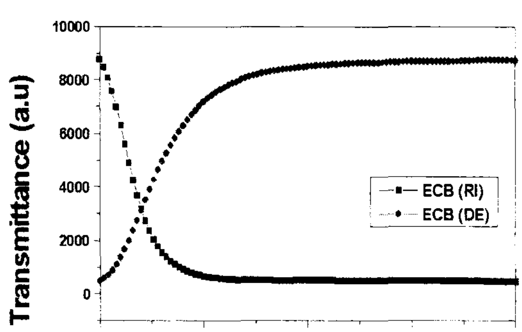
Type	V_{90}	V_{10}
45 °TN	0.83	3.37
67.3 °TN	0.84	3.06
ECB	0.89	3.78



(a) 45 ° TN mode



(b) 67.3 ° TN mode



(c) ECB mode

Fig. 3. Response characteristics of the TN cell with Δnd of NLCs on the rubbing PI surface.

Table 3. Response time of the TN cell with different NLCs and cell gap d on the rubbed PI surface.

Type	Response time		
	T_r	T_f	T
45 °TN	2.6	7.92	10.52
67.3 °TN	2.6	7.28	9.88
ECB	2.7	5.56	8.26

*T_r: rising time, T_f: falling time

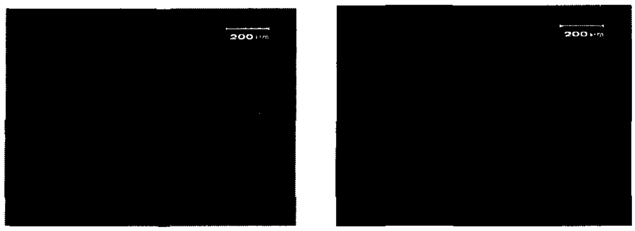
Figure 2 shows the V-T characteristics of TN cell with Δnd of NLCs on the rubbed PI surface with side chain. The stable transmittance characteristics were obtained in 45 ° TN, 67.3 ° TN and ECB Cell that have 1.6 μm cell gap. However, 45 ° TN had low transmittance comparing with others. Table 2 shows the threshold voltages of TN cell with Δnd of NLCs on the rubbed PI surface with side chain. As shown in Table 2, these operating modes had low critical voltages.

Figure 3 shows the response characteristics of TN cell with Δnd of NLCs on the rubbed PI surface with side chain. Good response characteristics were obtained in three operating modes. However, 45 ° TN mode had low transmittance. The reason is that the twisted value of nematic liquid crystal in 45 ° TN mode is smaller than that of NLC in other modes. Table 3 shows the response time of TN cell with different NLCs and cell gap *d* on the rubbed PI surface with side chain. Among them, the fastest response time was obtained in ECB mode. On the other hand, the response time of 45 ° TN is slower than others due to unfitting optics design between cell gap *d* and Δn.

3.2 Thermal ability of fast 90 ° TN cell

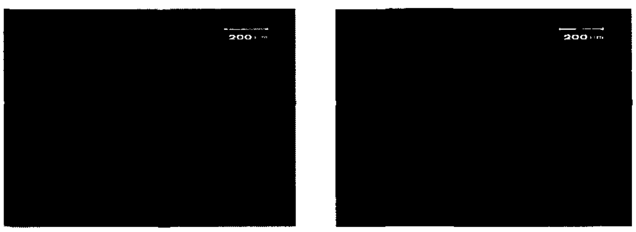
We investigated thermal ability of fast 90 ° TN-LCD. Thermal ability in the LCD is important to evaluate the LCD duration because LCD in the projection TV was exposed by high temperature. Figure 4 shows the micro-photographs of the no stressed 90 ° TN cell and stressed 90 ° TN cell on the rubbed PI surface for 12 h. The off-state alignment characteristic of the stressed 90 ° TN cell for 12 h was a bit reduced, compared with that of no thermal stressed TN cell, as shown in Fig. 4. It is shown that this was attributed to the increase of defects by the addition of thermal stress to the 90 ° TN cell.

Figure 5 shows the V-T curves of no stressed 90 ° TN cell and stressed 90 ° TN cells for 1 h, 6 h and 12 h on the rubbed PI surfaces. All 90 ° TN cells have about 2.0 μm cell gap. The transmittances of the 90 ° TN cells were decreased by increasing of the thermal stress as shown in Fig. 5. It is thought that this decrease of transmittance of the TN cells leads to the combination of



• Off State • On State

(a) No stressed TN cell



• Off State • On State

(b) Stressed TN cell for 12 h

Fig. 4. Microphotographs of TN cell (in crossed Nicols); (a) No stressed TN cell and (b) Stressed TN cell for 12 h.

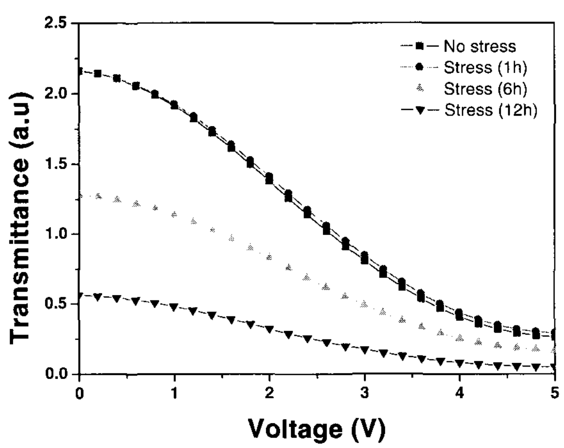


Fig. 5. The V-T curves of no stressed 90 °TN cell and stressed 90 °TN cells for 1 h, 6 h and 12 h on the rubbed PI surfaces.

the LC. As shown in the Fig. 5, it can be shown that there exist many defects after addition of thermal stress when no voltage is applied. It is thought that these defects caused the reduction of transmittance of the TN cells.

Table 4 shows the threshold voltage of TN cells for 1 h, 6 h and 12 h on the rubbed PI surfaces. The threshold voltage (V_{90}) of the stressed TN cell for 1 h was a little higher than that of no stressed TN cell, as shown in Table 4. However, the threshold voltage (V_{90}) of the stressed TN cell for 12 h was 0.762 V. But, this change of the threshold voltage is negligible enough to be considered the universal characteristic of the LCD evaluation. Therefore, the thermal stress to the TN cell on the list of the threshold voltage turned out to be insufficient.

Table 4. Threshold voltages of the four kinds of TN cell on the PI surface.

Type \ Voltage	V_{90}	V_{10}
No stressed TN cell	0.885	3.847
Stressed TN cell for 1 hr	0.878	3.877
Stressed TN cell for 6 hr	0.867	3.862
Stressed TN cell for 12 hr	0.762	3.703

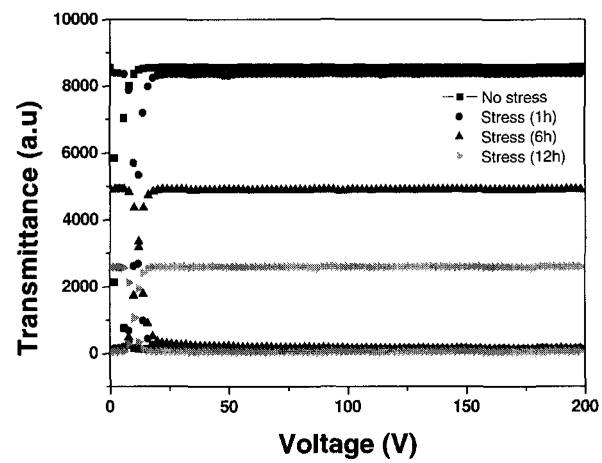


Fig. 6. The response time characteristics of no stressed TN cell and stressed TN cells for 1 h, 6 h, and 12 h on the rubbed PI surfaces.

Figure 6 shows the response time characteristics of no stressed TN cell and stressed TN cells for 1 h, 6 h, and 12 h on the rubbed PI surfaces. The transmittances of the TN cells were decreased by increasing of the thermal stress as shown in Fig. 6. Especially, the transmittance of the stressed TN cell for 12 h was decreased over 50 %. Above of all, it was indicated that LC aligning capability was decreased. It considered that long time thermal stress give rise to decrease of LC aligning capability. Because the duration of LC quality depends on the properties of matter, it is shown that the properties of matter were changed by the thermal stress.

Table 5 shows the response times of TN cells for 1 h, 6 h, and 12 h on the PI surfaces. As shown in the Fig. 6, it was indicated that the response time of the LC during the 12 h duration of stressed TN cell was a bit shorter. But, this change of the response time is negligible enough to be considered the universal characteristic of the LCD evaluation.

Table 5. Response times of the four kinds of TN cell on the PI surface.

Type \ Time	Rising time τ_r (ms)	Decay time τ_d (ms)	Response time τ (ms)
No stressed TN cell	5.1	6.55	11.65
Stressed TN cell for 1 hr	5.5	6.13	11.63
Stressed TN cell for 6 hr	7.2	5.97	12.97
Stressed TN cell for 12 hr	5.1	5.65	10.75

4. CONCLUSIONS

In this study, the EO characteristics of NLCs with different operating modes such as 45 ° TN, 67.3 ° TN and ECB on a rubbed PI surface were investigated. These operating modes had good EO characteristics. Especially, ECB cell had the fastest response time among them. Also, on the PI surface, alignment characteristic of TN cell of thermal stress produced much more defects, compared with the TN cell of no thermal stress. And the TN cell of the thermal stress showed similar threshold voltage and response characteristics, comparing with that of no thermal stress. However, the transmittance of the TN cell decreased as the thermal stress time increased. Therefore, when the LCD is stressed for the long duration by the high temperature, it is showed that the thermal stability is greatly reduced.

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