Rubbing Angle Effect on Response Time of the Fringe Field Switching (FFS) TFT-LCD using the Liquid Crystal with Negative Dielectric Anisotropy

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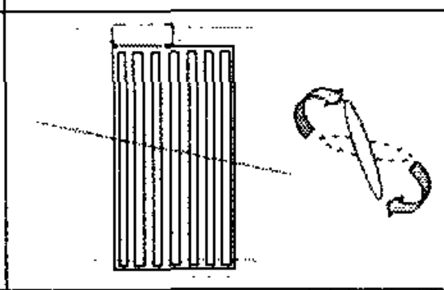
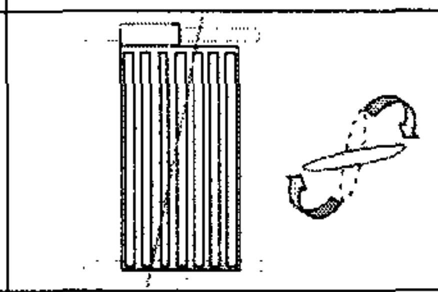
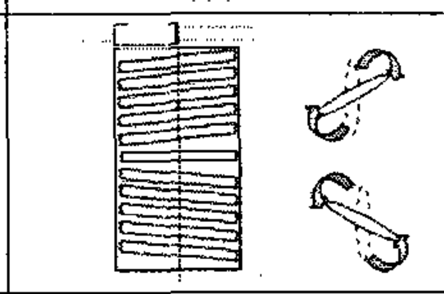
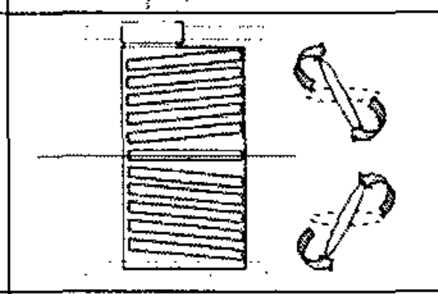
Abstract
We have studied on response time of the fringe-field switching (FFS) TFT-LCD using the LCs with negative dielectric anisotropy related to rubbing angle. Simulation and experimental results shows that when a rubbing angle approached 45°, a slope of voltage-dependent curve is decreased such that the operation voltage is increased, however the whole response characteristic between inter-gray levels have a trend to be fast.

1. Introduction
The fringe-field switching (FFS) TFT-LCD has been introduced and its excellent electro-optical characteristics, which exhibits high transmittance and wide viewing angle characteristic without using extra optical compensation films, have been spotlighted [1]. In addition, we recently reported that the pressure-resistant characteristic of the FFS mode was superior to that of the twisted nematic (TN) mode, and pen-based display systems using the FFS mode did not require any extra cover layer that could resist under external pressure [2, 3].

Those FFS modes are divided into two cases by dielectric anisotropy of LCs, in which one is the case using the LC with negative dielectric anisotropy (–LC) and the other is the case using the LC with positive dielectric anisotropy (+LC) as shown in table 1. In the case of FFS mode using –LC, it has merit of high transmittance that results from more real in-plane rotation of the LC directors than that of the case using +LC. However, the –LC material has generally low dielectric anisotropy (Δε) and high rotational viscosity (γ1) value compared with those of +LC. Therefore the FFS mode with –LC could not help having high operation voltage and especially slow response time property due to intrinsic character. Some years ago, we have reported that the electro-optical characteristic was dependent on rubbing angle in the case of in-plane switching (IPS) mode [4]. At now, we studied rubbing angle dependency on electro-optical characteristic of the FFS mode using –LC.

Table 1. Various cases of FFS mode.

	Negative LC	Positive LC	Remarks
Normal structure			High Transmittance
U-FFS structure			Color shift free
Feature	High Transmittance Dynamic stability	Fast Response Low Operation Voltage Low Cost	

2. Simulation Result
Generally in the IPS mode, the rubbing angle is known as very important parameter related to its electro-optical characteristic. Initial aligning direction of LC molecular against the electric field is decided about the rubbing angle and together with it, the induced force by the electric field is also determined. The initial force for rotating the LC director relates to molecular torque caused by electric field. The torque N is decided as below equation [4].

$$N = |\Delta\varepsilon\ (\vec{n}\cdot\vec{E})\ \vec{n}\times\vec{E}| = \Delta\varepsilon\ E_o^2 \sin 2\varphi$$

$\Delta\varepsilon$ is the dielectric anisotropy of LC molecule, E_o is the intensity of induced electric field and φ is an angle between the rubbing and field direction. From the above equation, when φ rises to 45°, the dielectric torque value becomes maximum and we can easily expect that the threshold voltage at which the transmittance begins to occur decreases as a result. However at the same induced voltage, the total amount of twist of the LC directors decreases, as rubbing angle is larger, so transmittance becomes smaller and operation voltage increases.

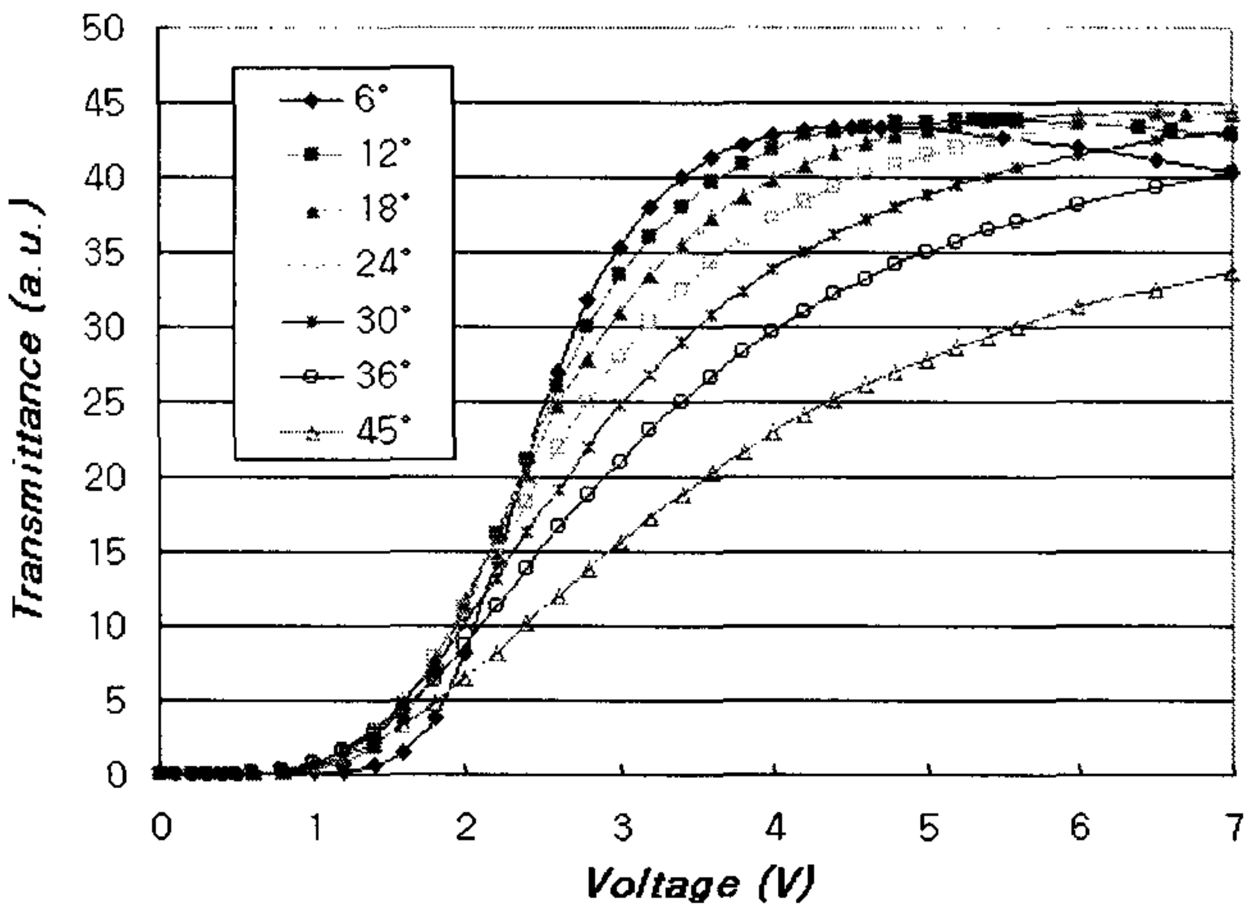


Figure 1. Calculated V-T characteristic curve about rubbing angle.

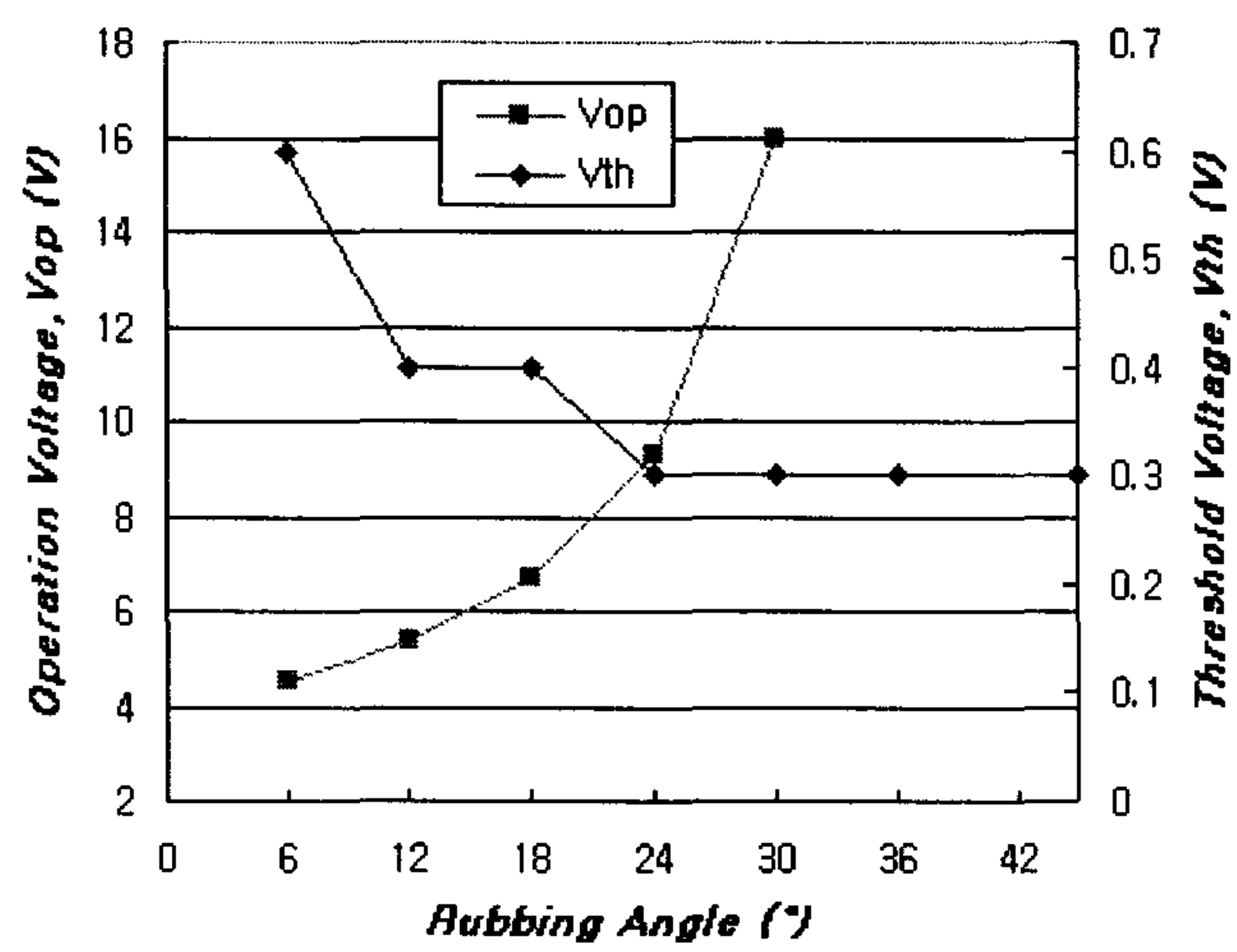


Figure 2. Calculated operation voltage and threshold voltage about rubbing angle.

We simulated voltage-dependent transmittance (V-T) characteristics of the FFS with –LC as varying rubbing angles, as shown in Fig. 1. The relationship between operation voltage and threshold voltage about rubbing angle is also shown in Fig. 2. For the simulation parameters of –LC, the dielectric anisotropy was -4.0 and the optical anisotropy was 0.768. The distance between slit on the pixel ITO layer was 5.5μm with electrode width of 3.0μm and cell gap was 3.9μm. As we already expected, the threshold voltage became smaller as the rubbing angle rose to 45° however the operation voltage became larger drastically. It is the same behavior as that in the IPS mode.

3. Experimental Result

We fabricated test panels that have three different rubbing angles, i.e. 12°, 30° and 45° with respect to the horizontal component of a fringe field, and evaluated electro-optical characteristics of them. The –LC material from Merck Co. was used and the cell gap was 3.9μm. The electrode structure is about the same as that of simulation condition.

- Voltage-Transmittance (V-T) characteristic

As rubbing angle increased to approach 45°, the slope of V-T characteristic curve became small and operation voltage increased. In the case of the cells with 30° and 45° rubbing angles, the transmittance continuously increased as data voltage increased, however that with 12° rubbing angle case saturated about 6~7V as shown in figure 3 and it was similar result with that of the simulation.

Generally the transmittance is maximized when an object with some birefringence is located with angle of 45° against one of transmission axis of the crossed polarizers. In the case of 45° rubbing, maximum twist angle of LC directors by electric field is 45°. So the higher the applied voltage is, the more LC directors become twisted close to 45°, i.e., the light transmittance keeps increasing. However, in the case of small rubbing angle like 12°, the LC directors twist more than 45° from transmission axis of the polarizer when data voltage increases, so maximum transmittance of the panel appears at the specific voltage level, and if data voltage is over that voltage, the transmittance decreases. It becomes clear by looking into the director profile at the edge of pixel electrode as shown in figure 4. The maximum twist angle inside a cell at that position is about 75°, 43°,

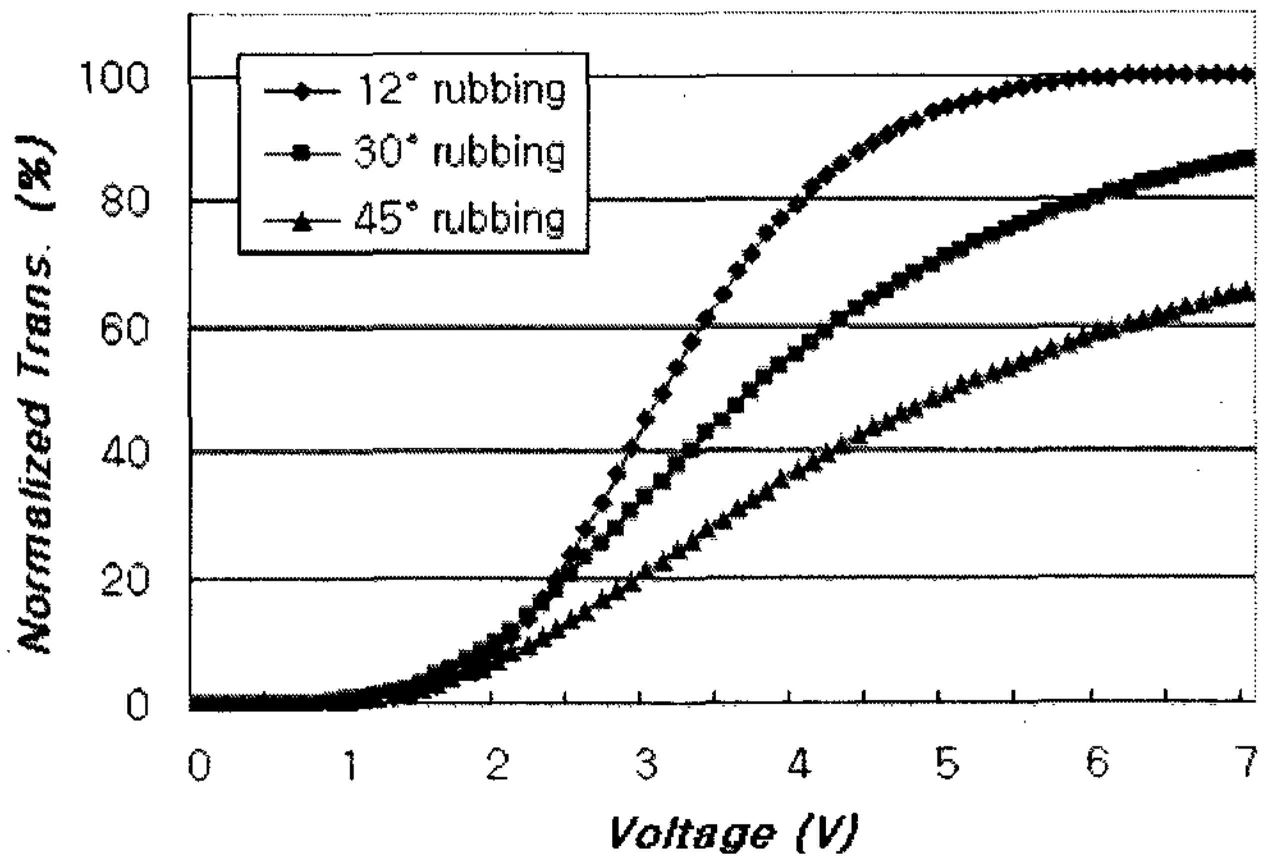


Figure 3. Measured V-T characteristic curve about rubbing angle.

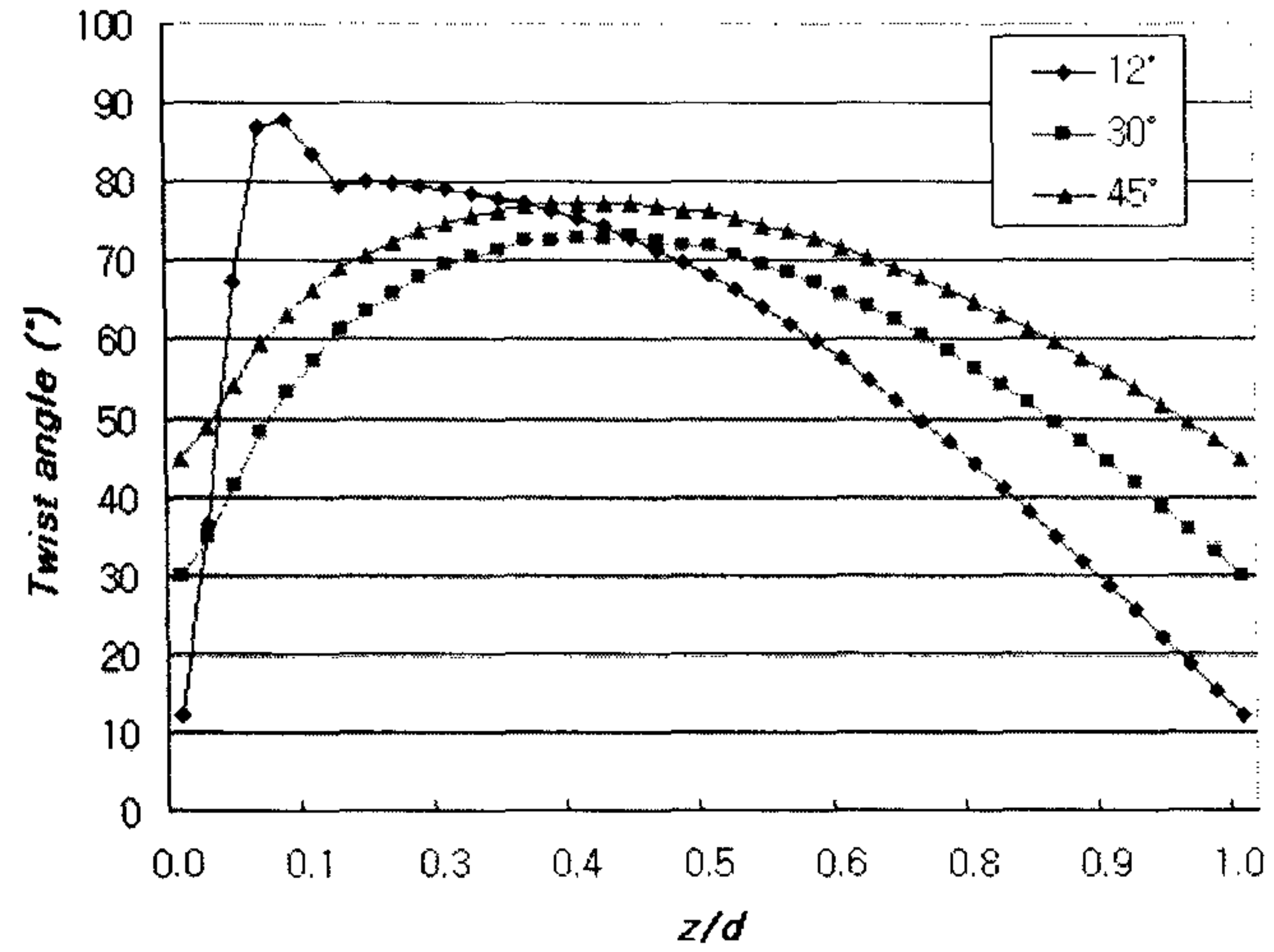


Figure 4. Twist angle comparison at the edge of slit about rubbing angle.

and 32° for 12°, 30°, and 45° rubbing angles, respectively. This explains low transmittance with large rubbing angle at given voltage.

- Response time characteristic

Previously, people have had an interest in fully on and off response time, i.e. the response time between V_{on} and V_{off} data voltage. However nowadays, response time between inter-gray levels is recognized as very important characteristic in increasing of demand for the video-quality image on TFT-LCD. For measurement of response time between inter-gray levels, we defined eight gray levels based on V-T curve shown in figure 3 and measured response time that was the transient interval between 10% and 90% transmittance of each gray level. In the case of 30° and 45°, we applied 7V as operation voltage and not voltage of the maximum transmittance because it was so high. The measurement results are shown in figure 5. We found that increasing of rubbing angle improved the response time characteristic, especially between mid-gray levels. In the case of the cells with large rubbing angle such as 30° and 45°, there were evident decrease of whole decaying time and in addition some rising time between mid-gray levels was decreased too. In terms of total response time between inter-gray levels, the range of 12° rubbing cell was distributed from 54.46ms to 109.42ms and its average was 83.60ms level. However in the case of 30° cell, minimum value was 51.50ms and maximum value was 89.31ms with average of 69.47ms. There is an improvement about 17% at the total response time between inter-gray levels through change only the rubbing angle form 12° to 30°. In addition, more

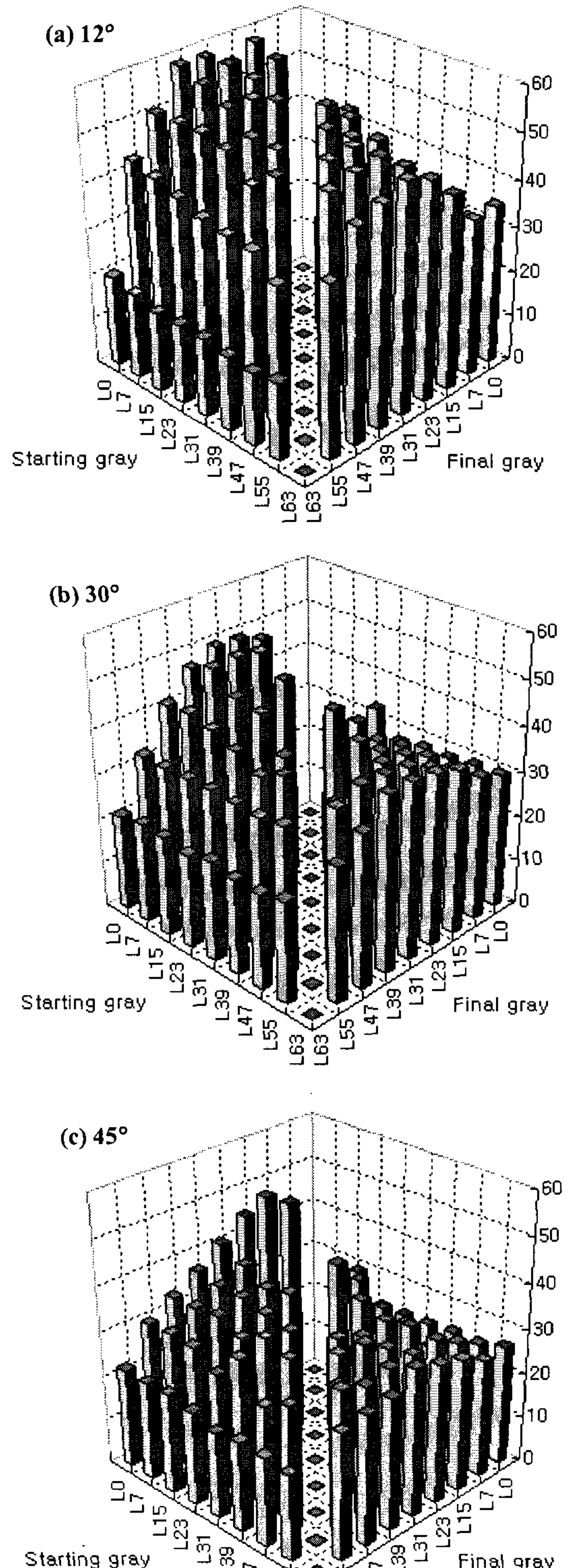


Figure 5. Measured response time characteristic between inter-gray levels about rubbing angle, i.e. (a) 12°, (b) 30° and (c) 45°.

betterment was appeared at the case of 45° cell, of which minimum value was 46.30ms and maximum value was 90.07ms with average of 60.07ms. It means that an improvement is reached 28% level of 12° rubbing at the total response time and its improvement is about 1.65 times than that of 30° rubbing cell.

4. Summary

We evaluated dependence on rubbing angle of the electro-optical characteristic of the FFS TFT-LCD using the –LC from simulation and measurement work. We found that threshold voltage decreased and operation voltage increased as rubbing angle rose to 45°. However we also confirmed the response time characteristic was improved between inter-gray levels. It is highly possible that we are able to utilize the rubbing angle as the key factor of achievement for the fast response time characteristic with the same materials and cell gap in the case of FFS TFT-LCD using –LC.

5. Acknowledgement

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6. References

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[4] S. H. Lee, et al. SID '97 Digest, p.711 (1997).