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Short Note

Rubbing Angle Effect on Response Time of the Fringe-Field Switching Nematic Liquid Crystal Display

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We have studied the response time of the fringe-field switching (FFS) nematic liquid crystal display (LCD) as a function of the rubbing direction. The results show that when a rubbing angle approached 45° with respect to an electric field, the response times between inter-gray levels tend to be fast. [DOI: 10.1143/JJAP.42.1290]

KEYWORDS: fringe-field switching, liquid crystal, response time, rubbing direction

Nowadays, the image quality of the nematic liquid crystal displays (LCDs) has been greatly improved with the adoption of new technologies such as in-plane switching (IPS),[1)] fringe-field switching (FFS)[2)] and multi-domain vertical alignment.[3)] However, the response time of the LCDs is still not fast enough to realize moving pictures perfectly.[4)] In order to achieve good moving pictures, a fast response time between grey levels is required. Previous works have reported that the IPS mode has an advantage in displaying moving grey levels compared with the twisted nematic mode[5)] and that the rubbing angle is known as a very important parameter relating to voltage dependent transmittance (V–T) curves.[6)] However, the relationship between rubbing angle and response time, including inter-grey levels, has not been reported.

In the FFS mode, the LCs are homogeneously aligned at the initial state with optic axis coincident with one of the transmission axes of the crossed polarizer, the same as that of the IPS mode. However, when a voltage is applied, a fringe electric field instead of an in-plane-field, is generated. The difference gives rise to different electrooptic behaviors from those of the IPS mode. Notably, in the FFS mode, they strongly depend on the dielectric anisotropy of the LC.[7,8)] The FFS mode using the LC with negative dielectric anisotropy ($-$LC) shows higher light efficiency than that using the LC with positive dielectric anisotropy (+LC). However, the $-$LC has intrinsically higher rotational viscosity than that of the +LC, indicating that displays with $-$LC shows relatively slower response times than those with +LC. Generally, the cell gap, an applied voltage and viscosity of the LC determine the response time of a cell. However, in this paper how the rubbing direction with respect to an electric field affects the response time, in particular between grey levels when using the $-$LC, will be demonstrated.

Three test cells with different rubbing angles of 12°, 30° and 45° with respect to the horizontal component of a fringe field were fabricated. In addition, the three test cell' electro-optical characteristics were evaluated. Here, the cell structure, including electrodes, is the same as in previous report[7)] and the $-$LC is used ($\Delta n = 0.077$ at $\lambda = 589\,\text{nm}$, $\Delta\varepsilon = -4.0$, $\gamma = 136\,\text{mPa·s}$) with a cell gap of $3.9\,\mu\text{m}$. Figure 1 shows measured V–T curves with applied voltages of up to 7 V. The steepness of the V–T curves decreases with

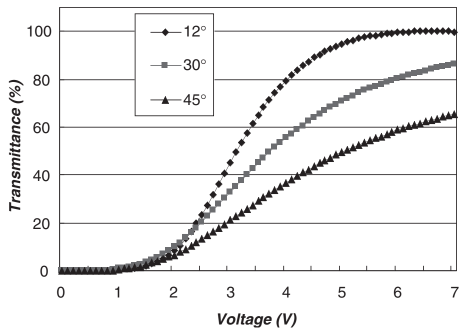

Fig. 1. Voltage-dependent transmittance curves ranging up to 7 V measured as a function of the rubbing angle with respect to the horizontal component of a fringe electric field.

increasing rubbing angles, i.e., the threshold voltage decreases and the operating voltage increases as the rubbing angle varies from 12° to 45°. In addition, as the rubbing approaches 45°, light transmittance decreases, because the maximum twist angle by applying an electric field cannot reach 45°. The results suggest that when choosing a rubbing angle, the light transmittance as well as V–T shape should be considered. For a 30° rubbing angle, a higher applied voltage of over 7 V is necessary to get the same light transmittance as that of a 12° cell. In general the rising response time is inversely proportional to the square of the intensity of electric field. In other words, the stronger the intensity of electric field, the larger the dielectric torque N is, since the dielectric torque N is given by as follows:[6)]

$$N = |\Delta\varepsilon(\boldsymbol{n}\cdot\boldsymbol{E})\boldsymbol{n}\times\boldsymbol{E}| = \Delta\varepsilon E_0^2 \sin 2\varphi$$

where $\Delta\varepsilon$ is the dielectric anisotropy of LC molecule, $\boldsymbol{n}$ is a LC director, E_0 is the intensity of the induced electric field $\boldsymbol{E}$ and φ is the angle between the rubbing and field direction. In order to verify the rubbing angle effect on response time, the maximum applied voltage was 7 V for all three cells. However, the 7 V corresponds to the voltage to rotate the LC director by 45° in average and by less than 45° for the 12° and the 30° rubbed cells, respectively because the transmittance is proportional to $\sin^2(2\Psi)$ in the device where Ψ is an angle between the LC director and the transmission axis of the crossed polarizers.[2)] First we have divided the V–T curve into 64 gray levels equally from black (L0) to white (L63), that is, the transmittance intervals, $T(n+1) - T(n)$, are constant where $T(n)$ are the transmittance for n-th level. And

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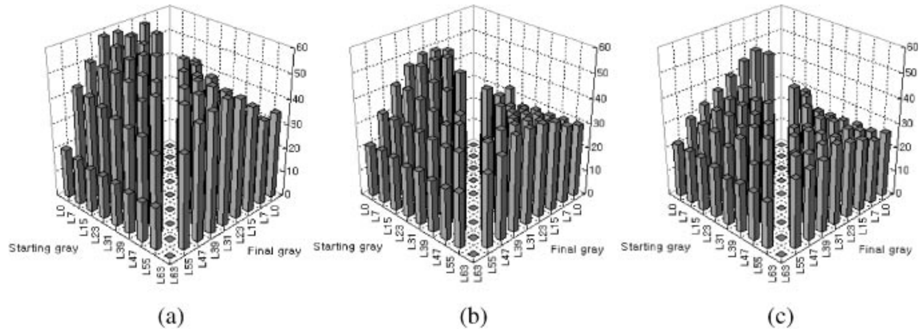

Fig. 2. Measured response times between gray levels when the rubbing angle to with respect to horizontal component of a fringe electric field is (a) 12°, (b) 30°, and (c) 45°.

then we have measured the response time by applying and reducing a voltage with a minimum jump of 8 gray levels, as shown in Fig. 2. This indicates that the degree of rotation of the LC director is not the same each other for the three cell at given applied voltage. Here, the response time is transient interval between 10% and 90% light transmittance of each gray level. We found that increasing the rubbing angle improved the response time characteristic, especially between mid-gray levels. Considering rising response time, τ_r, for the cell with a rubbing angle of 12°, the maximum rising time was 58.6 ms and many inter-gray level response times were over 50 ms, whereas for the cell with a rubbing angle of 45°, it was 51.3 ms and only a few gray response times were over 40 ms. This is an interesting result that the τ_r becomes fast with increasing rubbing angle although the smaller voltage is applied to rotate the LC director to the same degree for the 45° rubbed cell than for the 12° rubbed cell. Analyzing the response time in terms of the value of τ_{max}/τ_{min}, it was 3.57, and 2.77 for rubbing angles of 12°, and 45°, respectively. The results reveal that the rising response times become fast along with increasing rubbing angle because the dielectric torque, N, is larger for the cell with a rubbing angle of 45° than for one with a rubbing angle of 12° and also the difference in τ_r between gray levels is reduced. For decaying response times (τ_d), the decreasing rates are much more obvious with increasing rubbing angles. For the cell with a rubbing angle of 12°, the τ_d varies from 20.5 ms to 54.2 ms, however, in the case of the cell with a rubbing angle of 30°, it varies from 20.4 ms to 46.7 ms. By further increasing the rubbing angle to 45°, the maximum τ_d is below 40 ms and it ranges from 20.4 ms to 38.8 ms. The results indicate that increasing the rubbing angle decreases the response time in whole grays as well as reducing the difference in response times between gray levels. Finally, evaluating the total response time ($\tau_r + \tau_d$) between inter-gray levels, it ranges from 54.5 ms to 109.4 ms with an average of 83.6 ms for the 12° rubbing cell, but ranges from 51.5 ms to 89.3 ms with an average of 69.5 ms for the 30° rubbing cell, which is an improvement about 17% for the total response time between inter-gray levels. This is achieved by changing only the rubbing angle from 12° to 30°. In addition, more improvement was evident in the 45° rubbing cell; the minimum value was 46.3 ms and maximum value was 90.1 ms with an average of 60.1 ms, which is a 28% reduction of the 12° rubbed cell's the total response time.

In summary, we investigated how the rubbing angle affects response time in the FFS mode using the −LC. The experimental results show that as the rubbing angle increases to 45° with respect to the horizontal component of a fringe field, the response time between inter-gray levels decreases and the difference in response times between gray levels is also reduced, allowing advantages to display moving picture of gray levels. In addition, in the FFS mode the rubbing angle is also an important factor in reducing the response time.

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