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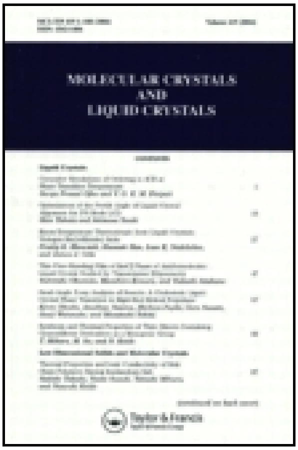

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Evaluation of Reverse Twist Stability in an IPS Mode

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Evaluation of Reverse Twist Stability in an IPS Mode

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A reverse twist defect deteriorates a picture quality of an In-Plane Switching (IPS) mode display. We have proposed a simple method to evaluate the reverse twist stability using a sine curve director profile approximation. The calculated stability has been corresponded to the observed phenomena. Using this method, the stability dependence on the device parameters can be investigated with facility and the deterioration due to the reverse twist defect can be predicted. In the present study, the stability dependence on the rubbing angle, the driving voltage and the cell gap has been examined. The preferable cell gap condition has been suggested to prevent the reverse twist defect.

Keywords: LCD; IPS; In-Plane Switching; reverse twist; defect

1. INTRODUCTION

An IPS mode is a top-rated candidate for a large size liquid crystal display because of its exclusive wide viewing angle properties. However, a picture quality deterioration caused by the reverse twist defect is reported as a shortage of an IPS device[1, 2]. This phenomenon occurs when the device panel face is pushed at "ON state". Figure 1 shows the formation of the reverse twist defect schematically. There exist inherent reverse twist domains in the corners indicated in the figure. The reverse twist domains expand their area owing to the liquid crystal flow when the push is released. Arrows in the figure indicate

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motions of disclination curves observed when the device is pushed on the right side of the pixel. Each disclination curve is stabilized forming an arch. The pixels around the push point are shaded by these stabilized disclination arches. In the case that the device is prepared with a small rubbing angle, the defect remains remarkably long.

Suzuki *et al.*[2] have calculated the one-dimensional reverse twist profiles by a conventional director simulation on the appropriate initial conditions. They have obtained the reverse twist profiles at higher voltage than the driving voltage. However, the reverse twist stability, which corresponds to the defect's lifetime, cannot be estimated by their method.

We propose a simple method to evaluate the reverse twist stability using a sine curve director profile approximation. Using this method, the stability dependence on the device parameters can be investigated with facility. Then, the device design can be conducted including the defect prevention.

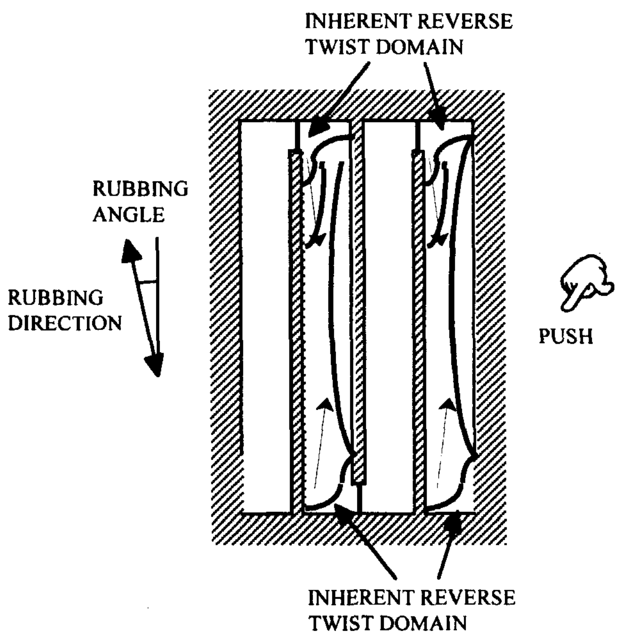

FIGURE 1 Schematic diagram of the reverse twist defect formation.

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2. CALCULATION METHOD

The one-dimensional free energy G of an IPS mode liquid crystal layer can be calculated by the following equations,

$$G=\int_0^d g(z)dz$$
$$g(z)=\frac{1}{2}K_{22}\left(\frac{d\phi(z)}{dz}\right)^2-\frac{1}{2}\Delta\varepsilon\varepsilon_0E^2\sin^2\phi(z) \tag{1}$$

, where d is a cell gap, K_{22} is a twist elastic constant, z is a coordinate along the liquid crystal layer thickness, $\phi(z)$ is an azimuthal angle between the electric field E and the director, $\Delta\varepsilon$ is a dielectric anisotropy, and ε_0 is an absolute dielectric constant. The pretilt angle is ignored in this expression. The director profiles can be obtained by minimizing G in the conventional director simulation.

First, twist director profiles at "ON state" have been calculated. The reverse twist profile can be calculated as a local minimum state on the appropriate initial director profile. The uniform lateral electric field is assumed. The cell gap d is set at the value calculated by the equation,

$$\frac{\Delta nd}{\lambda}=\frac{1}{2} \tag{2}$$

,where Δn is a birefringence of the liquid crystal and λ is the wavelength of the incident light.

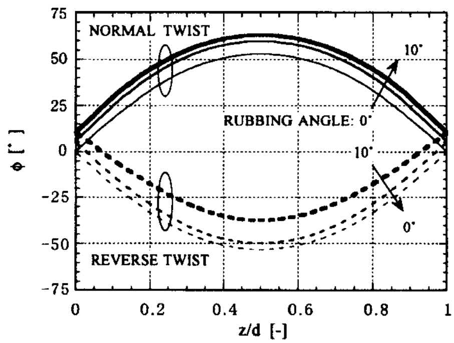

FIGURE 2 Calculated normal- and reverse- twist director profiles.

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Figure 2 shows the calculated director profiles on the various rubbing angle conditions. Reverse twist profiles are indicated by broken curves, while normal twist profiles are indicated by solid curves. In the case of the rubbing angle over 10°, the stable reverse twist profile can not be obtained on any initial director profiles.

We have applied a sine curve director profile approximation to the expression of all states including a transition state in order to estimate the reverse twist stability. The sine curve profile is expressed by

$$\phi(z) = (\phi_{center} - \phi_{rubbing})\sin\left(\frac{\pi z}{d}\right) + \phi_{rubbing} \tag{3}$$

,where ϕ_{center} is an azimuthal angle of the director at z = d/2 and $\phi_{rubbing}$ is the rubbing angle. Using above approximation, the director profile can be characterized by one variable, ϕ_{center}. Therefore, ϕ_{center} dependence of G can be calculated with facility.

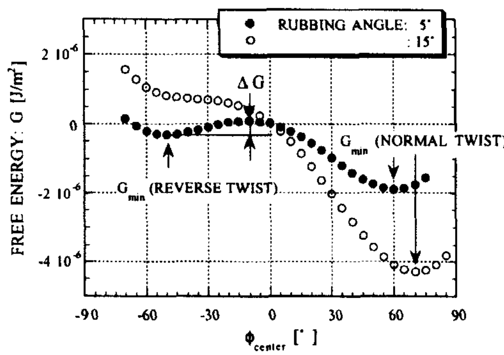

FIGURE 3 ϕ_{center} dependence of the free energy G.

Figure 3 shows ϕ_{center} dependence of G in the case of the rubbing angle 5° and 15°. The G - ϕ_{center} curve of 5° (closed circle) has two minimum points corresponding to the reverse twist and the normal twist, while the G - ϕ_{center} curve of 15° (open circle) has only one minimum point corresponding to the normal twist. The free energies of these minimum points have been compared with those obtained by the conventional director simulation. Figure 4 shows the free energies calculated by two methods on the various rubbing angle conditions. The free energies obtained by the conventional simulation (broken curves)

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have been reappeared satisfactorily with those calculated using the sine curve approximation (solid curves). This result has proved that the sine curve approximation described above is a valuable method.

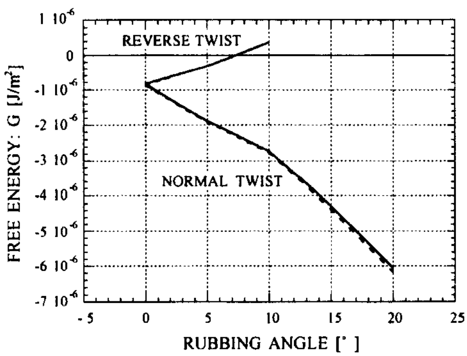

FIGURE 4 Free energy dependence on the rubbing angle.
solid curve: the sine curve approximation
broken curve: the conventional simulation

Figure 3 shows that there exists a saddle point between the two minimum points in the case of the rubbing angle 5°. An energy difference (ΔG) between the local minimum point for the reverse twist and the saddle point can be treated as an energy barrier of the transition from the reverse twist state to the normal twist state. Therefore, we have chosen ΔG as a parameter to represent the reverse twist stability. In the case of the rubbing angle 15°, ΔG can not be obtained because the local minimum point for the reverse twist does not exist. In this case, ΔG is defined as zero.

3. REVERSE TWIST STABILITY ON VARIOUS CONDITIONS

Using above calculation method, the reverse twist stability dependence on the device parameters such as rubbing angle, applied voltage, and cell gap, has been investigated.

Figure 5 shows the ΔG dependence on the rubbing angle and the applied voltage. The "ON state" voltage (V_{max}) is set at the value calculated on each rubbing angle condition. In the case of the rubbing angle over 10°, G_{min} for the reverse twist does not exist at any applied voltage (shown as ΔG = 0), which means that the reverse twist is unstable. Therefore, the reverse twist defect disappears quickly on this condition. When the rubbing angle is set at 10° or less, ΔG has a certain value at "ON state", which means that the reverse twist defect remains stably for a long time. However, the defect disappears when the applied voltage is reduced even on this condition. These results correspond to the observed phenomena shown in refs. 1 and 2. Therefore, ΔG is a useful parameter to predict the formation of the reverse twist defect.

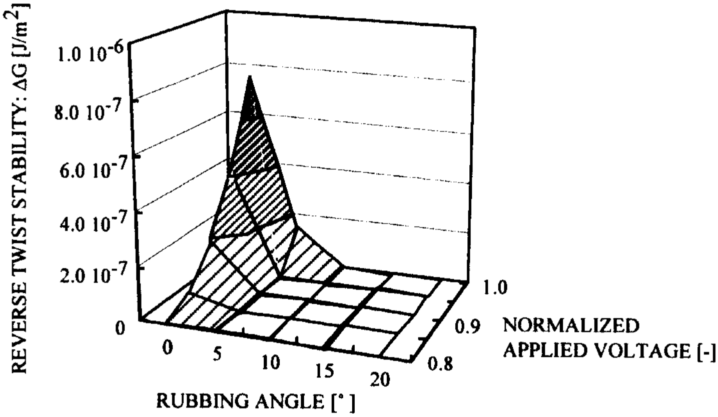

FIGURE 5 ΔG dependence on the rubbing angle and the applied voltage.

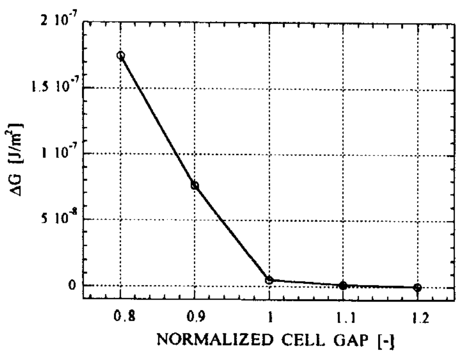

FIGURE 6 ΔG dependence on the normalized cell gap.

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Next, the ΔG dependence on the cell gap has been investigated. Figure 6 shows ΔG dependence on the cell gap. The cell gap value calculated by eq.(2) is chosen as the standard cell gap (d_{std}). The rubbing angle is 10°. The applied voltage is set at the V_{max} value calculated on each cell gap condition. ΔG reduces when the cell gap is set larger. Since the driving voltage becomes small with a large gap cell, the reverse twist stability decreases. ΔG becomes zero in the case of $1.2 \cdot d_{std}$, which means that the reverse twist is unstable and the defect disappears quickly.

Figure 7 shows the approaches to prevent the reverse twist defect. Three voltage-transmittance curves are described in this figure. Solid curves indicate the case of the rubbing angle 10° and a broken curve indicates the case of 15°. The calculation results have shown that there are at least three approaches to prevent the reverse twist defect, that is, to enlarge the rubbing angle (a), to lower the driving voltage (b), and to enlarge the cell gap (c). Obtained transmittance varies in these three approaches as shown in Figure 7. The transmittance becomes higher when the cell gap is set larger than d_{std}[3]. Approach (b) is inevitably accompanied by the transmittance reduction. The change of the rubbing angle induces a little increase of the driving voltage and deterioration of the symmetric viewing angle properties. Approach (c) is preferable to prevent the reverse twist defect, since it enhances the transmittance at the same time.

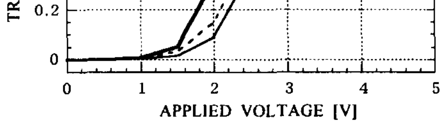

FIGURE 7 Approaches to prevent the reverse twist defect.

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4. SUMMARY

The reverse twist stability ΔG has been proposed as a parameter to judge the reverse twist defect formation. A sine curve director profile approximation has been introduced for the new simple calculation method to evaluate ΔG. The calculated stability has been corresponded to the observed phenomena. ΔG dependence on the device parameters, such as the rubbing angle, the driving voltage and the cell gap, has been investigated. The preferable cell gap condition has been suggested to prevent the reverse twist defect.

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