Ultra-Low Driving Voltage in Quasi-Twisted Nematic Mode Using Weak / Strong Anchoring Hybrid Alignment Surface

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ABSTRACT

A hybrid twisted nematic cell was designed using strong and weak polar anchoring surfaces. The LC director distribution without the voltage was the same as a conventional 90° TN. Electro-optical properties were numerically analyzed and a driving voltage of less than 1/5 of the TN cell was obtained.

1. INTRODUCTION

Some types of liquid crystal displays using a weak anchoring alignment surface have been proposed to reduce a driving voltage. Recent years, we have proposed a novel type of the TN LCD with a combination of weak and strong anchoring surfaces. The homogeneous orientation without the applied voltage changes to the TN orientation and the transmittance increases from 0% to almost 100% with increasing the twist angle by applying low voltage [1]. In addition, hybrid aligned nematic (HAN) cells using strong and weak polar anchoring surfaces have been proposed and quasi-homogeneous and -homeotropic alignment cells which have no threshold voltage were numerically analyzed [2,3].

On the other hand, a "twisted hybrid aligned (THA) [4]" cell or a "hybrid twisted nematic (HTN) [5]" cell has been proposed. Such an LC cell has both a hybrid alignment and a twisted director configuration. A faster response and a lower driving voltage were obtained in comparison with a conventional TN mode.

In this study, the HTN cell has been designed using strong polar anchoring of the planar surface and weak polar anchoring of the homeotropic surface. Without the voltage, the LC director distribution was exactly the same as that in a conventional 90° TN cell. Therefore, we call this LC cell as a quasi-twisted nematic (Q-TN) cell. An LC director distribution and an electro-optical property were numerically analyzed.

2. PRINCIPLE

2.1 Free energy of HTN cell

Figure 1 shows a schematic model of HAN and Q-TN cells. The planar alignment surface has infinite strong polar and azimuthal anchoring strengths. In addition, azimuthal easy axes of two substrates are orthogonal. When only the polar anchoring of the homeotropic surface becomes lower than critical one, the tilt angle on the surface is 0° and the LC director configuration becomes the same as a conventional 90° TN cell, as shown in Fig. 1(b).

A total free energy per unit area F in the HTN cell is represented,

$$F = F_{\text{surface}} + F_{\text{bulk}} + F_{\text{electric}}$$

$$F_{\text{surface}} = \frac{1}{2}W_{\text{p\_0}}\sin^2(\theta_0 - \theta(0)) + \frac{1}{2}W_{\text{p\_d}}\sin^2(\theta_{\text{d}} - \theta(d))$$

$$\begin{aligned} F_{\text{bulk}} + F_{\text{electric}} &= \int_0^d \frac{1}{2}\left\{(K_{11}\cos^2\theta + K_{33}\sin^2\theta)\left(\frac{d\theta}{dz}\right)^2 \right. \\ &+ (K_{22}\cos^2\theta + K_{33}\sin^2\theta)\cdot\cos^2\theta\left(\frac{d\phi}{dz}\right)^2 \\ &\left. -2K_{22}\frac{2\pi}{P_0}\cos^2\theta\left(\frac{d\phi}{dz}\right) + K_{22}\left(\frac{2\pi}{P_0}\right)^2 - \varepsilon_0(\varepsilon_\perp + \Delta\varepsilon sin^2\theta)\left(\frac{dV}{dz}\right)^2\right\} \quad (1) \end{aligned}$$

where K_{11}, K_{22} and K_{33} are splay, twist and bend elastic constants, P_0 is the helical pitch of the LC, θ is the tilt angle, ϕ is the twist angle, d is the thickness of the LC layer, and W_p is the polar anchoring strength of each substrate. The LC director distribution is estimated by minimizing a total free energy F under the voltage application by a finite difference method. A transmittance is estimated using Jones matrix.

2.2 LC director distribution in Q-TN cell

We estimate the tilt angle $\theta(d)$ on the homeotropic surface as a function of the polar anchoring W_{p_d} shown

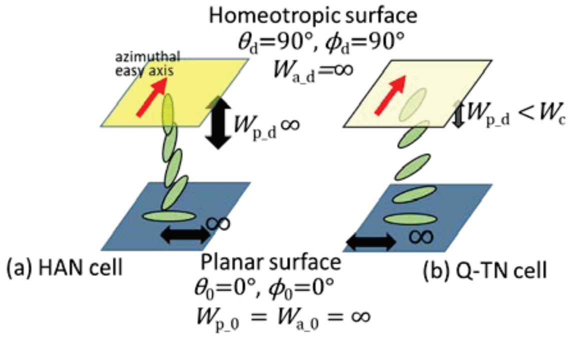

Fig. 1 Schematic model of (a) HAN cell and (b) Q-TN cell.

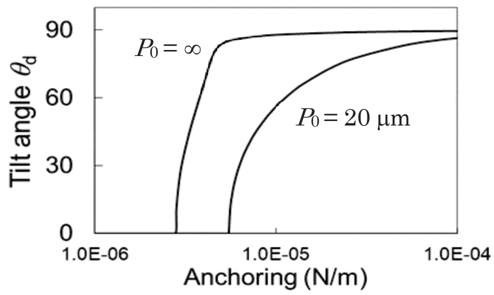

Fig. 2 Polar anchoring strength vs. tilt angle θ_d

in Fig 2. Typical nematic elastic constants, K_{11} of 14, K_{22} of 10 and K_{33} of 20 pN are used in these curves. The cell thickness is 5 μm. The tilt angle θ_d decreases with decrease of anchoring. In the case of $P_0 = \infty$, θ_d is zero when W_{p_d} is less than 2.8×10^{-6} N/m (=K_{11}/d). that is, the Q-TN cell can be obtained. When P_0 is 20 μm (=d/4) , θ_d becomes zero when W_{p_d} is less than 5.5×10^{-6} N/m

3. ELECTRO-OPTICAL PROPERTIES

LC director distributions of θ and ϕ in the Q-TN cell are shown in Fig. 2 under the voltage application. P_0 is infinite and W_{p_d} is 2.8×10^{-6} N/m. The tilt angle on the weak anchoring surface immediately increases by the voltage. When the applied voltage is higher than 1 V, the tilt angle on the weak anchoring surface is 90°, which is almost the same distribution in the HTN cell using strong anchoring interface. Figure 4 shows electro-optical properties in the Q-TN and a conventional 90° TN cell in a normally white mode. Δn is 0.095 which gives the 1st Morgan minimum condition at 550 nm. A threshold voltage V_{90} and a driving voltage V_{10} in the Q-TN cell are 0.28 V and 0.43 V, respectively. Those voltage is extremely low comparing to V_{90} of 1.5 V and V_{10} of 2.3 V in a conventional 90° TN cell using same LC physical properties. VT curves with red, green and blue colors are also shown in Fig. 4. The wavelength dependence is small as well as a conventional TN cell. This result indicates that the transmission light is colorless in gray scale.

In the practical case for the homeotropic alignment surface, it must be difficult for the strong azimuthal

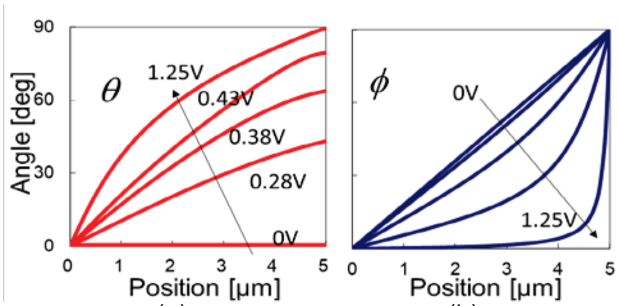

Fig.3 Director distribution of (a)θ and (b)ϕ.

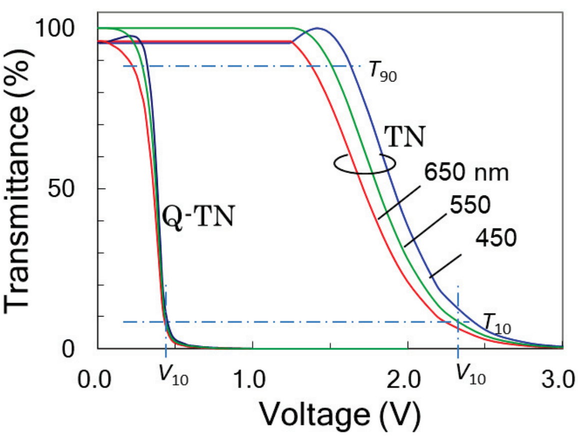

Fig. 4 VT curves of RGB in Q-TN and 90° TN cells.

anchoring and the weak polar anchoring to coexist. When the azimuthal anchoring strength W_a decreases to 1.0×10^{-5} N/m (=5K_{22}/d), the twist angle decreases to 74.4° and the transmittance is about 95.3 % with no voltage application. V_{10} slightly increases to 0.67 V comparing to the Q-TN cell with infinite W_a, as shown in Fig. 5. If W_a decreases to 2.0×10^{-6} N/m (=K_{22}/d), the twist angle is 0° and the cell shows homogeneously orientation configuration. Therefore, we estimate the Q-TN cell with P_0 of 20 μm which results in 90° twist angle at any azimuthal anchoring strength. VT curves of TN and Q-TN cells with P_0 of 20 μm are also shown in Fig. 5. It is known that the short pitch LC increases the driving voltage of the TN cell. V_{90} and V_{10} in the Q-TN cell are 0.92 V and 1.62 V, respectively.

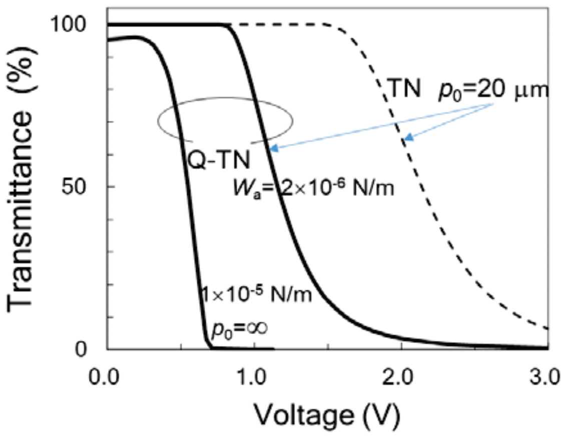

Fig. 5 VT curves of TN and Q-TN cells with P_0 of 20 μm.

4. CONCLUSIONS

The Q-TN which has the HAN configuration of easy axes and the LC director distribution of a conventional 90° TN cell has been proposed by using strong polar anchoring of the planar surface and weak polar anchoring of the homeotropic surface. The LC director distribution and the electro-optical property were numerically analyzed. When the azimuthal anchoring of both substrates is infinite, the driving voltage V_{10} in the Q-TN cell is less than 1/5 of that in a conventional 90° TN cell using same LC physical properties, for example V_{10} of 0.46 V. The wavelength dependence is very small.

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